



**DEPARTMENT OF THE ARMY**  
PROJECT MANAGER, HEAVY LIFT HELICOPTER, AMC  
PO BOX 209, ST. LOUIS, MISSOURI 63166

31 January 1975

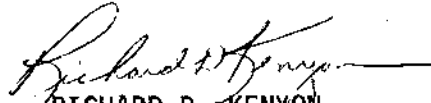
The Heavy Lift Helicopter (HLH) program was originally conceived and approved by DOD and Congress as a pure technology program to develop, fabricate, and evaluate through demonstration testing the critical components of a helicopter capable of lifting 22.5 tons. Subsequently, as a logical follow-on effort, an austere prototype was added to provide for the essential flight validation of these components at a time when the Government's cost exposure was at a minimum and to permit a user evaluation of the HLH concept. The technical objectives of this advanced development effort were to:

- Provide the Government with improved technology and reduce the risk associated with large payload helicopters.
- Provide spin-off technology to other Government and civilian agencies.
- Advance the level of industry expertise in large helicopter components.

Since the HLH program is the primary Army program focused upon advancing the frontiers of helicopter technology, the design objectives for each of the components were purposely set very high to ensure that a really significant improvement would be made in the state-of-the-art. The philosophy of minimizing the Government's investment to attain this technology has been maintained throughout the program by limiting the development and testing to be accomplished to the minimum essential to demonstrate feasibility. A very closely integrated, interdependent R&D program has resulted which, after 4 years of concentrated effort and an investment of less than \$200M, is now nearing completion.

All indications are that this program will be successful. All of the objectives are being attained and a quantum jump forward is being made in rotary wing technology. The attached brochure provides a summary of progress to date and a synopsis of the more significant technical benefits which will be realized.

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as

  
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## TABLE OF CONTENTS

I. PURPOSE	I
II. SUMMARY	II
III. MAJOR HLH TECHNOLOGY MILESTONES	V
IV. OVERVIEW	VII
A. ROTOR SYSTEM	1
B. DRIVE SYSTEM	17
C. FLIGHT CONTROL SYSTEM	35
D. CARGO HANDLING SYSTEM	59
E. ENGINE	73
F. AIRFRAME	82
G. SUBSYSTEMS	93
H. MATERIALS	99
I. FLIGHT TEST PROGRAM	104
J. RELIABILITY, AVAILABILITY AND MAINTAINABILITY	108
K. PERFORMANCE	111

I. PURPOSE.

THE PURPOSE OF THIS BOOK IS TO DOCUMENT THE ADVANCEMENTS THAT THE HEAVY LIFT HELICOPTER (HLH) ADVANCED DEVELOPMENT PROGRAM AND AUSTERE PROTOTYPE PROGRAM HAVE ACHIEVED AND PLAN TO ACHIEVE FROM THE INITIATION OF THE EFFORT IN JUNE 1971 UNTIL ITS PRESENTLY SCHEDULED COMPLETION IN OCTOBER 1976.

ONE OF THE MAJOR OBJECTIVES OF THE PROGRAM WAS TO ADVANCE HELICOPTER TECHNOLOGY. IT IS HOPED THAT THIS DOCUMENT ILLUSTRATES THESE ADVANCEMENTS.

## II. SUMMARY.

THE HLH PROGRAM WAS CONCEIVED AND APPROVED BY CONGRESS AS A PURE TECHNOLOGY PROGRAM TO DEVELOP AND DEMONSTRATE, BY FLIGHT TESTING AN AUSTERE PROTOTYPE, THE CRITICAL COMPONENTS OF A HELICOPTER CAPABLE OF LIFTING 22.5 TONS. SINCE 1971, DOD HAS COMMITTED \$189.9 MILLION TO ATTAIN THIS TECHNOLOGY WITH NO COMMITMENT TO ANY FOLLOW-ON DEVELOPMENT PROGRAM. THE FACT THAT THE ARMY IS UNABLE TO PROGRAM FUNDS TO DEVELOP AND PRODUCE A HELICOPTER EMPLOYING THIS TECHNOLOGY DURING THIS PERIOD WHEN SO MANY OTHER HIGH PRIORITY DEVELOPMENTS ARE UNDERWAY, IN NO WAY ALTERS THE OBJECTIVES OF THE ORIGINAL PROGRAM OR REDUCES THE DESIRABILITY OF ATTAINING ITS TECHNICAL BENEFITS, NOR THE STATED ARMY REQUIREMENT FOR PRODUCTION HEAVY LIFT HELICOPTERS. THE HLH PROGRAM IS THE ONLY DOD HELICOPTER PROGRAM WHICH IS MAKING A SIGNIFICANT ADVANCEMENT IN THE STATE-OF-THE-ART IN HELICOPTER TECHNOLOGY. IT IS PROVIDING OVER A TWO-FOLD INCREASE IN LIFT CAPABILITY OF THE EXISTING LARGEST PROGRAMED HELICOPTER AND INCLUDES MANY NEW DESIGN CONCEPTS, ADVANCED MATERIALS, AND PRODUCTION TECHNIQUES WHICH RESULT IN SUBSTANTIAL COST AND WEIGHT REDUCTION WHILE ADDING A NEW DIMENSION IN FLIGHT SAFETY. VALIDATION OF THESE ADVANCES WILL BE COMPLETED BY FLIGHT TESTING. SOME OF THE MORE SIGNIFICANT FEATURES ARE:

1. THE FUSELAGE IS THE LARGEST STRUCTURE EVER BUILT OF BONDED ALUMINUM HONEYCOMB, SELECTIVELY INCORPORATING HIGH MODULUS COMPOSITES FOR TAILORED STIFFENING AND NEW VIBRATION REDUCTION TECHNOLOGY.

2. THE LARGE FIBERGLASS ROTOR BLADE, WHICH FEATURES ADVANCED AIRFOILS, THICKNESS AND TWIST DISTRIBUTIONS, PROMISES TO BE THE MOST AERODYNAMICALLY

EFFICIENT EVER DEVELOPED. THE CONSTRUCTION IS EXPECTED TO PROVIDE AN EXCEPTIONALLY LONG LIFE, INCLUDING AN INHERENTLY FAIL-SAFE FIBERGLASS SPAR, A WRAP-AROUND FAIL-SAFE ROOT END, AND A NONCORROSIVE, DAMAGE TOLERANT NOMEX AFT FAIRING.

3. HUB AND UPPER CONTROLS WHICH FEATURE A STRUCTURE OF TITANIUM WITH SOLID ELASTOMER BEARINGS AND HIGH MODULUS FIBER REINFORCING REQUIRING NO LUBRICATION. THEY INCLUDE THE MOST COMPLETE FAILURE PROTECTION SYSTEM EVER PRODUCED IN HELICOPTERS USING REDUNDANCY AND INCIPIENT FAILURE INDICATORS.

4. A LIGHT BUT POWERFUL DRIVE SYSTEM UTILIZING VASCO X-2 STEEL, HIGH SPEED TAPERED ROLLER BEARINGS, AN INTEGRAL COOLING AND LUBRICATION SYSTEM WITH FULL FLOW DEBRIS DETECTION, A GRAPHITE ROTOR BRAKE AND TITANIUM ROTOR SHAFTS.

5. A TOTAL FLY-BY-WIRE REDUNDANT, HIGHLY FAIL-SAFE FLIGHT CONTROL SYSTEM WHICH WILL PROVIDE SIGNIFICANT WEIGHT REDUCTION, EXCEPTIONAL STABILITY AND PRECISION CONTROL, INCREASED RELIABILITY, REDUCED VULNERABILITY, AND FLYING QUALITIES WHICH ALLOW AN ALL-WEATHER FLIGHT CAPABILITY.

6. A PNEUMATICALLY OPERATED CARGO HANDLING SYSTEM FEATURING DUAL-POINT SUSPENSION PROVIDING GREATER EXTERNAL LOAD STABILITY, BETTER MISSION EFFECTIVENESS AND SYSTEM SAFETY.

7. ENGINES WHICH FOR THE FIRST TIME HAVE BEEN DEVELOPED FOR HIGH EFFICIENCY IN THE HELICOPTER OPERATING MODE OF 50-60 PERCENT POWER. THEY ARE UNIQUE IN THEIR POWER RANGE, BEING THE MOST POWERFUL AIRCRAFT TURBOSHAFT ENGINE AVAILABLE TODAY IN THIS COUNTRY WITH POTENTIAL APPLICATION TO OTHER AIRCRAFT, SURFACE SHIPS, AND COMMERCIAL PROGRAMS. THEY HAVE BEEN OPTIMIZED TO PROVIDE LOW FUEL

CONSUMPTION OVER A WIDE RANGE OF POWER SETTINGS AND ARE SIGNIFICANTLY MORE EFFICIENT THAN MOST ENGINES OPERATIVE TODAY. THEY ARE BEING DESIGNED TO HAVE LOW NOISE EMISSIONS, WITH FEW CHEMICAL POLLUTANTS AND NO VISIBLE SMOKE, AND MAKE EXTENSIVE USE OF NEW MANUFACTURING TECHNIQUES TO REDUCE COSTS.

8. DIGITAL ELECTRONIC SPEED CONTROL AND POWER MANAGMENT WITH FLY-BY-WIRE COCKPIT TO ENGINE CONTROL INPUTS.

### III. MAJOR HLH TECHNOLOGY MILESTONES.

THE MAJOR HEAVY LIFT HELICOPTER TECHNOLOGY MILESTONES ALREADY ACCOMPLISHED AND THOSE PLANNED TO BE ACCOMPLISHED IN THE REMAINDER OF THE ADVANCED DEVELOPMENT (AD) PROGRAM ARE SHOWN IN FIGURE 1 PLOTTED AGAINST DOLLAR EXPENDITURES. THESE SIGNIFICANT EVENTS WILL FURTHER HELICOPTER TECHNOLOGY WITH MAJOR SPIN-OFFS TO OTHER MILITARY AIRCRAFT SYSTEMS AS WELL AS COMMERCIAL APPLICATIONS.

# III MAJOR HLH TECHNOLOGY MILESTONES

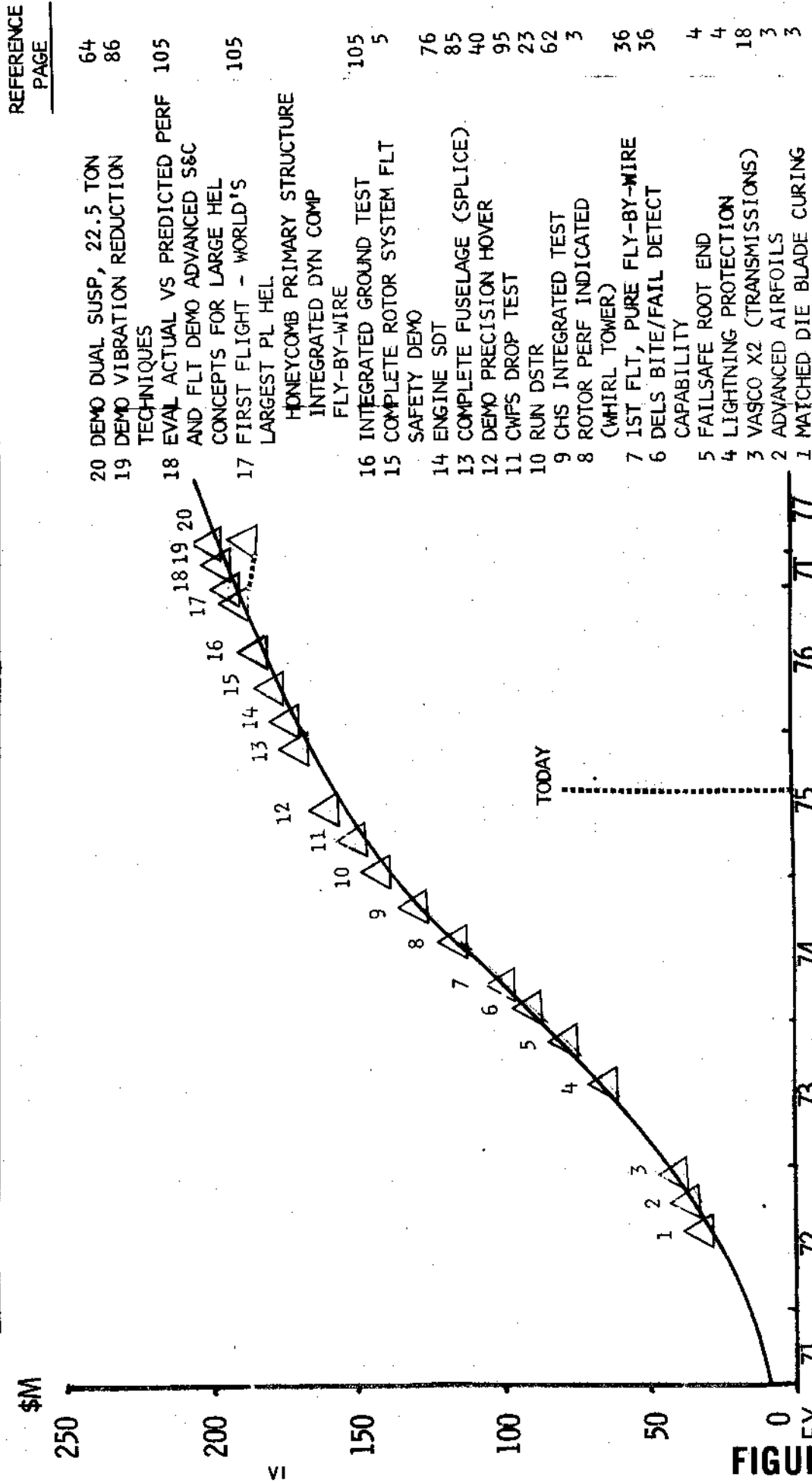


FIGURE 1

#### IV. OVERVIEW

A. ROTOR SYSTEM

## A. ROTOR SYSTEM

### PAST TECHNOLOGY ACCOMPLISHMENTS - ROTOR HUB AND UPPER CONTROLS

#### COMPLETE DEMONSTRATION OF LARGE NONLUBRICATED SHEAR BEARING - JANUARY 1974

THE HLH ROTOR HUB DESIGN CRITERIA REQUIRED THAT ALL HUB PARTS BE DESIGNED TO REQUIRE NO LUBRICATION. TO FULFILL THIS REQUIREMENT, A LARGE, DRY LUBRICANT SELF-ALIGNING BEARING WAS DEVELOPED TO TRANSMIT THE HIGH VERTICAL SHEAR LOADS GENERATED BY A LARGE HELICOPTER, FIGURE 2. SEVERAL DESIGN ITERATIONS RESULTED IN A HIGH CONFORMITY DRY LUBRICANT BEARING WHICH DEMONSTRATED OVER A 1,200-HOUR ENDURANCE LIFE AND IS TOLERANT TO A SAND AND DUST ENVIRONMENT.

BOEING VERTOL DOCUMENT NO. - D301-10111-3 DATED AUGUST 1974

#### FRETTING PROTECTION DEMONSTRATION - SEPTEMBER 1974

THE BASIC HLH ROTOR HUB AND UPPER CONTROL DESIGN MAKES EXTENSIVE USE OF THE HIGH STRENGTH TO WEIGHT RATIO OF TITANIUM, FIGURE 3. DURING TESTING OF SEVERAL OF THE TITANIUM COMPONENTS, SEVERE FRETTING PROBLEMS WERE ENCOUNTERED. AS A RESULT OF THESE PROBLEMS, EXTENSIVE INVESTIGATION AND TESTING OF FRETTING INHIBITORS HAVE RESULTED IN DEVELOPMENT AND DEMONSTRATION OF ADVANCED NEW TECHNOLOGY FRETTING INHIBITORS.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

## A. ROTOR SYSTEM (CONTINUED)

### PAST TECHNOLOGY ACCOMPLISHMENTS - ROTOR BLADE

#### USE OF COMPOSITES AS PRIMARY STRUCTURE - JANUARY 1972

DESIGNED AND DEVELOPED A BLADE STRUCTURE USING A COMBINATION OF FIBERGLASS AND GRAPHITE COMPOSITES TO TAKE ADVANTAGE OF THEIR OUTSTANDING PROPERTIES, SUCH AS FATIGUE STRENGTH, STIFFNESS AND DAMAGE RESISTANCE, FIGURE 4. THIS PERMITTED A BLADE WEIGHT REDUCTION OF APPROXIMATELY 20 PERCENT WHEN COMPARED TO EXISTING STATE-OF-THE-ART MATERIALS AND FABRICATION TECHNIQUES.

BOEING VERTOL DOCUMENT NO. - D301-10227-1 DATED JULY 1974

#### MATCHED DIE BLADE CURING - JANUARY 1972

DEVELOPED TECHNIQUES AND APPROACHES REQUIRED FOR FABRICATING COMPLEX ADVANCED COMPOSITE BLADE DESIGNS TO ASSURE VOID FREE BONDS BETWEEN NOMEK, COMPOSITES, AND TITANIUM COMPONENTS, FIGURE 5. THIS PERMITS EXCELLENT BLADE MANUFACTURING REPEATABILITY WITH REGARD TO TOLERANCES.

BOEING VERTOL DOCUMENT NO. - D301-10280-1 DATED JUNE 1974

#### ADVANCED AIRFOILS - MARCH 1972

NEW HYBRID AIRFOILS WERE DEVELOPED AND INTEGRATED INTO THE HLH BLADE. THESE AIRFOILS ALONG WITH IMPROVED TWIST PROFILES RESULTED IN A FIGURE OF MERIT OF .767 WHICH WAS DEMONSTRATED ON THE WHIRL TOWER VERSUS A GOAL OF .751, FIGURE 6. THIS ACHIEVEMENT IS A SIGNIFICANT IMPROVEMENT OVER STATE-OF-THE-ART BLADES (ROTOR FIGURE OF MERIT = .692) AND PERMITS A PAYLOAD INCREASE FOR THE HLH OF APPROXIMATELY 4 TONS. THE ADVANCED AIRFOILS ARE ALSO EXPECTED TO RESULT IN INCREASED AIRSPEED AT WHICH RETREATING BLADE STALL IS ENCOUNTERED DUE TO THEIR GREATER LIFT CAPABILITY MEASURED IN TWO-DIMENSIONAL WIND TUNNEL TESTS.

BOEING VERTOL DOCUMENT NO. - D301-10071-1 DATED JULY 1972 AND D301-10201-2  
DATED SEPTEMBER 1974

#### A. ROTOR SYSTEM (CONTINUED)

##### DAMAGE RESISTANCE - JANUARY 1973

THE STRUCTURAL AND MATERIAL APPROACHES DEVELOPED IN THE HLH BLADE HAVE RESULTED IN A BLADE THAT IS VERY RESISTANT TO FOREIGN OBJECT DAMAGE, BATTLE DAMAGE, AND CRACK PROPAGATION, FIGURE 7. THIS PERMITS BALLISTIC SURVIVABILITY TO 23 MM PROJECTILES VERSUS THE REQUIREMENT OF 7.62 MM. THIS DAMAGE TOLERANT DESIGN ALSO PROVIDES 200 HOURS SAFE FLIGHT AFTER A MATERIAL FAILURE WOULD BE DETECTABLE.

BOEING VERTOL DOCUMENT NO. - D301-10227-1 DATED JULY 1974

##### LIGHTNING PROTECTION - JANUARY 1973

NEW LIGHTNING CONDUCTOR TECHNIQUES WERE DEVELOPED AND TESTED ON FULL-SIZE BLADE SECTIONS RESULTING IN PROTECTION TECHNIQUES APPLICABLE TO OTHER AIRCRAFT SYSTEMS.

BOEING VERTOL DOCUMENT NO. - D301-10240-2 DATED MAY 1974.

##### TITANIUM FORMING - FEBRUARY 1973

DEVELOPED TECHNOLOGY FOR THE LARGEST DRAPE FORMED TITANIUM SHEETS USED IN THE AIRCRAFT INDUSTRY TO SHAPE THE COMPLEX CONFIGURATIONS REQUIRED FOR THE LEADING EDGE PROTECTION OF ROTOR BLADES, FIGURE 8.

BOEING VERTOL DOCUMENT NO. - D301-10280-1 DATED JUNE 1974

##### FAIL-SAFE ROOT END RETENTION - JUNE 1973

A NEW ROOT END CONCEPT AND LAY-UP PROCEDURE WAS DEVELOPED WHICH DISTRIBUTES STRUCTURAL LOADS IN A REDUNDANT MANNER THUS ALLOWING OVER 100 HOURS OF SAFE FLIGHT OPERATIONS AFTER FAILURE OF ONE PRIMARY LOAD LUG, FIGURE 7. TESTS HAVE DEMONSTRATED FLIGHT LOAD CAPABILITY AFTER LOSS OF 25-40 PERCENT OF THE PRIMARY LOAD PATH.

BOEING VERTOL DOCUMENT NO. D301-10146-1 DATED SEPTEMBER 1973.

A. ROTOR SYSTEM (CONTINUED)

FUTURE TECHNOLOGY GOALS - ROTOR HUB AND UPPER CONTROLS

SWASHPLATE ENDURANCE TEST - MAY 1975

THE DEVELOPMENT OF A SWASHPLATE FOR THE HLH REQUIRES DEMONSTRATION OF VERY LARGE BALL BEARING OPERATION IN LIGHTWEIGHT INSTALLATIONS, FIGURE 9. THIS TECHNOLOGY ADVANCEMENT WILL BE DEMONSTRATED IN MID 1975.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

COMPOSITE STIFFENING OF SWASHPLATES - MAY 1975

A SIGNIFICANT IMPROVEMENT IN THE EFFICIENCY OF SWASHPLATE DESIGN TECHNOLOGY IS BEING ACHIEVED BY THE USE OF BORON COMPOSITE STIFFENING RINGS IN COMBINATION WITH A BASIC METAL RING DESIGN, FIGURE 10. THIS ALLOWS FOR THE MOST EFFICIENT USE OF MATERIAL PROPERTIES IN THE DESIGN OF VERY LARGE RING STRUCTURES. THE FINAL DEMONSTRATION OF THIS APPROACH WILL BE ACCOMPLISHED IN MID 1975.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

COMPLETE ROTOR FAIL-SAFETY DEMONSTRATION - AUGUST 1975

A MAJOR HLH PROGRAM GOAL UNPARALLELED BY ANY AIRCRAFT PROGRAM TO DATE WAS TO DEVELOP THE DESIGN AND STRUCTURAL TECHNOLOGY TO MEET A REQUIREMENT THAT ALL CRITICAL LOAD CARRYING COMPONENTS WILL HAVE A FAIL-SAFE DESIGN.

DESIGN APPROACHES RESULTED IN THE CAPABILITY FOR COMPONENTS TO OPERATE A MINIMUM OF 100 HOURS AFTER ONE OF THE REDUNDANT LOAD PATHS FAILS AND A 30-HOUR CAPABILITY FOR COMPONENTS USING A FAILURE DETECTION DEVICE. SOME COMPONENTS HAVE ALREADY DEMONSTRATED THIS FAIL SAFETY AND THE FINAL DETERMINATION OF THIS CAPABILITY WILL BE ACCOMPLISHED IN MID 1975, FIGURES 3 AND 9.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

#### COMPACT ELASTOMERIC BEARINGS

AN IMPORTANT PART OF THE HLH ROTOR DESIGN WAS THE DEVELOPMENT OF A LOW MAINTENANCE ROTOR HUB. THIS WAS ACCOMPLISHED BY DEVELOPING A HUB USING COMPACT LIGHTWEIGHT ELASTOMERIC BEARINGS, FIGURE 3A. THE USE OF THESE BEARINGS PERMITS A 60 PERCENT REDUCTION IN HUB PARTS AND COMPLETE ELIMINATION OF ALL LUBRICATION SYSTEMS FROM THE HUB. BENCH TESTS HAVE DEMONSTRATED THE STATIC AND DYNAMIC CAPABILITY OF THESE BEARINGS AS WELL AS THE CAPACITY TO FUNCTION EVEN THOUGH FAILED. THE FINAL VERIFICATION OF THE COMPACT ELASTOMERIC BEARING CONCEPT WOULD HAVE BEEN ACHIEVED DURING HLH FLIGHT TESTING.

## A. ROTOR SYSTEM (CONTINUED)

### FUTURE TECHNOLOGY GOALS - ROTOR BLADE

#### FLIGHT DEMONSTRATION OF LARGE COMPOSITE BLADES - MARCH-OCTOBER 1976

ONE OF THE MOST IMPORTANT TECHNOLOGY ADVANCEMENTS IN THE HLH PROGRAM IS THE DEVELOPMENT OF LARGE COMPOSITE BLADES FABRICATED WITH MATCHED DIES, FIGURES 4, 5, AND 7. THIS TECHNIQUE PRODUCES REPEATABILITY OF PROPERTIES SUCH AS WEIGHT, BALANCE, AND SHAPE, THUS PROVIDING BLADES WITH IMPROVED TRACKING CAPABILITY AND REDUCED VIBRATION CAPABILITY. THIS IS ESPECIALLY IMPORTANT ON LARGE HELICOPTERS WHICH OPERATE AT LOW ROTOR FREQUENCIES. FLIGHT DEMONSTRATION OF THESE CHARACTERISTICS WILL BE ACCOMPLISHED IN MID 1976.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

#### FLIGHT VERIFICATION OF FIGURE OF MERIT - MARCH-OCTOBER 1976

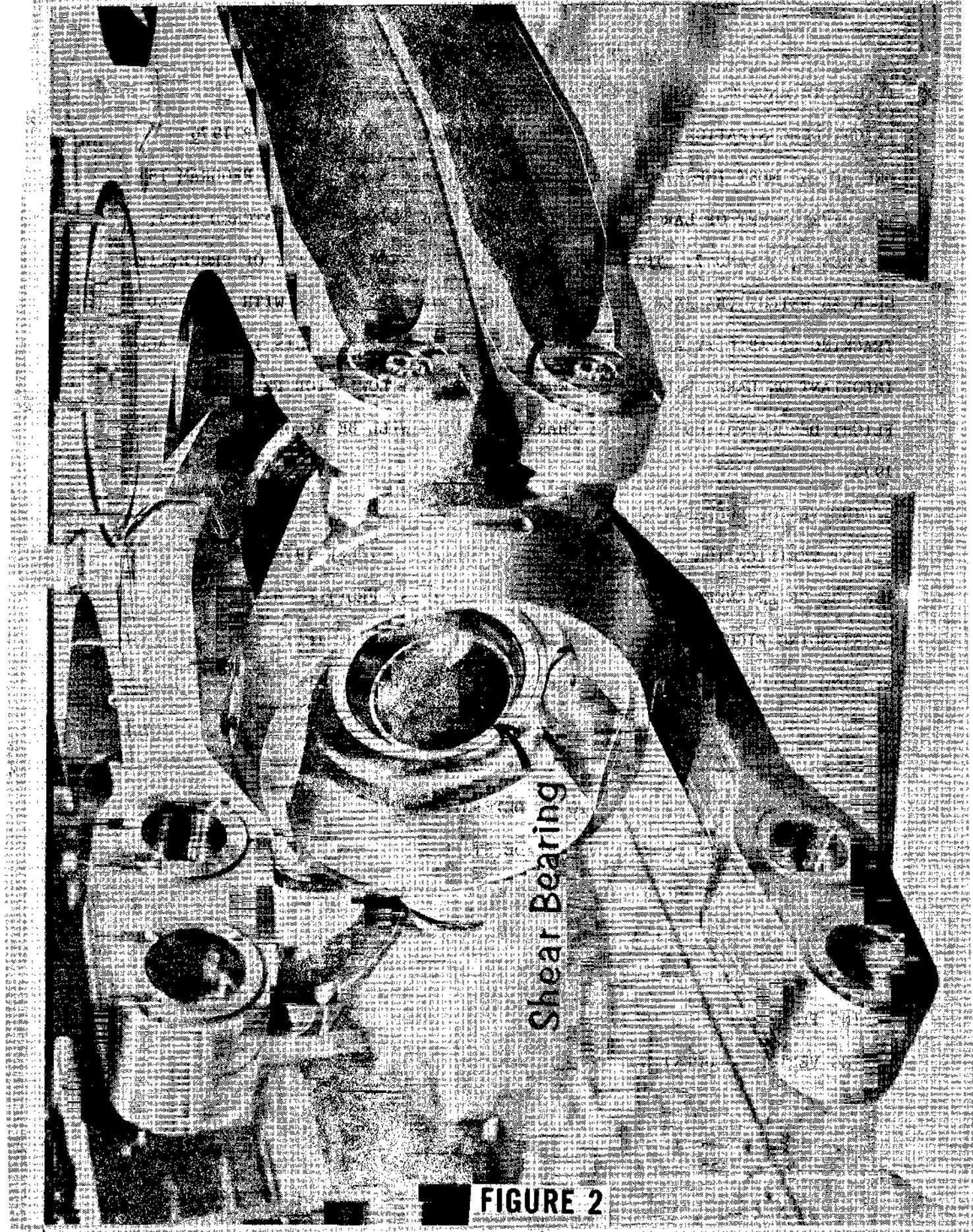
THE USE OF ADVANCED AIRFOILS WITH IMPROVED TWIST PROFILES HAVE RESULTED IN OUTSTANDING FIGURE OF MERIT ACHIEVEMENTS (.767) BEING INDICATED DURING WHIRL TESTING, FIGURE 6. THE FINAL VERIFICATION OF THE ACHIEVEMENTS WILL BE ACCOMPLISHED DURING FLIGHT TESTING WHILE OPERATING WITH SPECIFIC PAYLOADS. THIS TESTING WILL BE ACCOMPLISHED DURING MID 1976.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

#### FLIGHT VERIFICATION OF IMPROVED BLADE STALL AIRSPEEDS - MARCH-OCTOBER 1976

THE TWO-DIMENSIONAL CHARACTERISTICS OF THE ADVANCED AIRFOILS HAVE INDICATED A SUBSTANTIAL IMPROVEMENT IN  $C_L$  MAX WHICH SHOULD BE REFLECTED IN INCREASED BLADE STALL LIMITED AIRSPEEDS. THE VERIFICATION OF THIS WILL BE ACCOMPLISHED DURING FLIGHT TESTING IN 1976.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

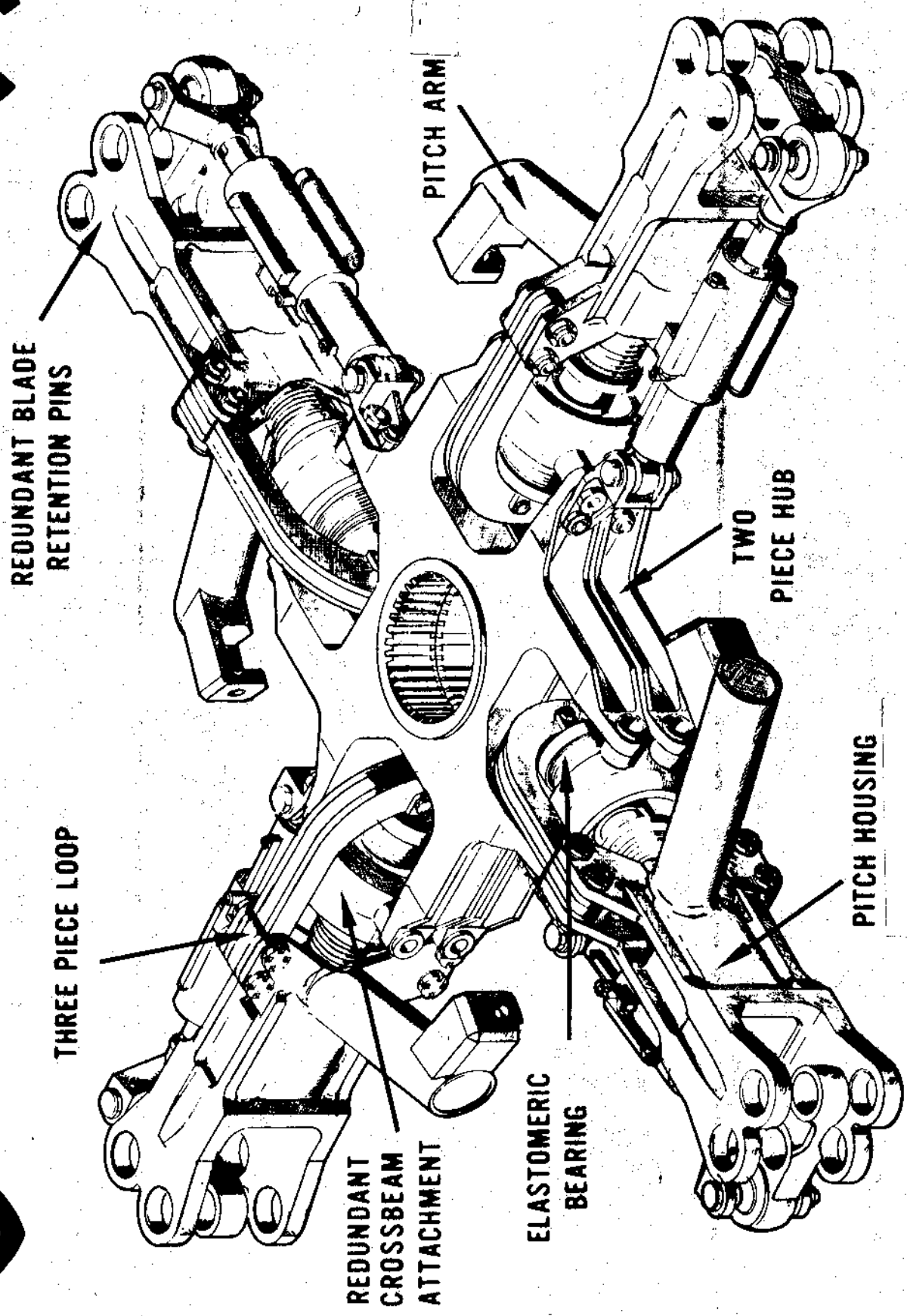
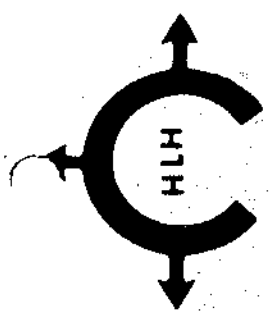


Shear Bearing

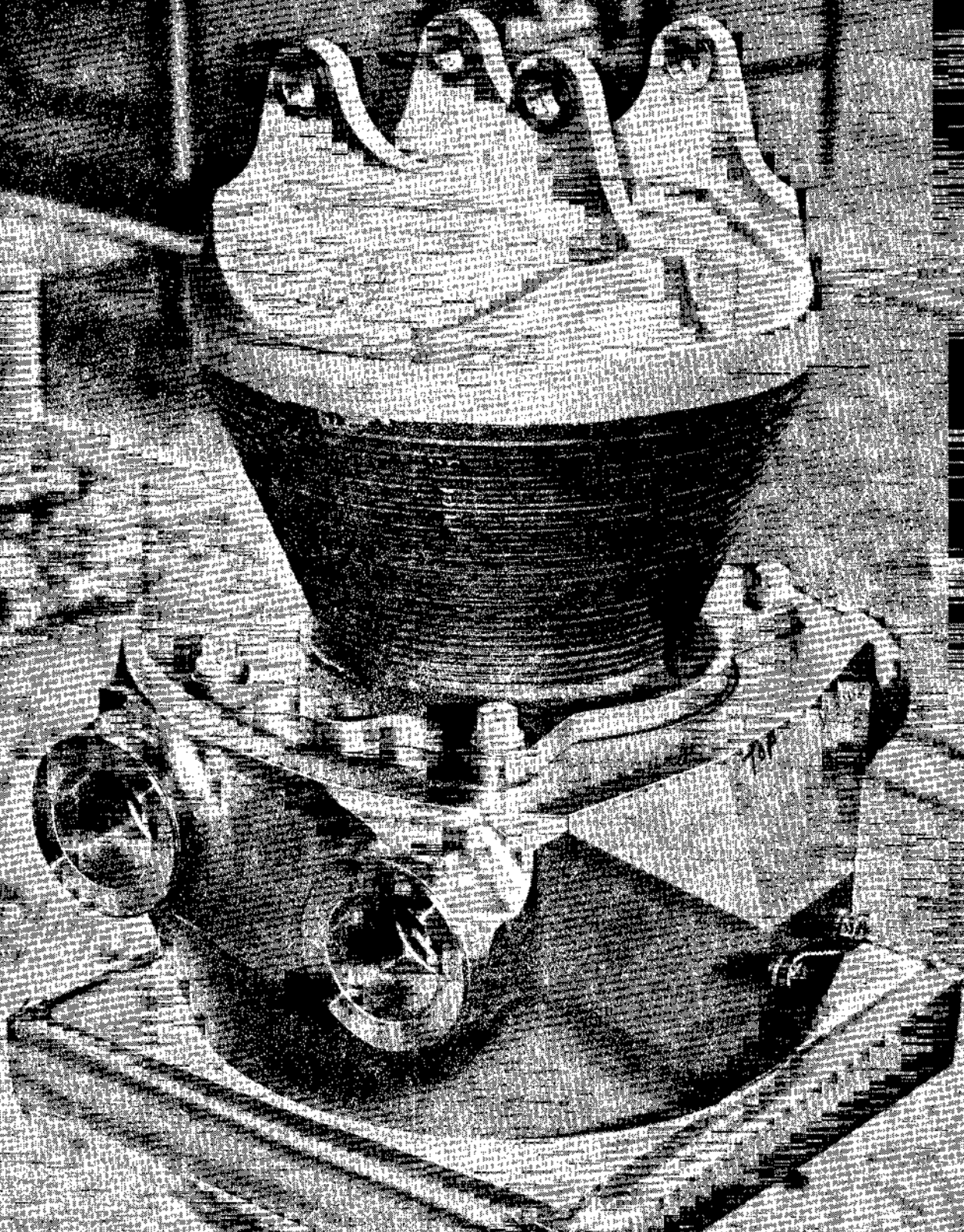
FIGURE 2



# ROTOR HUB

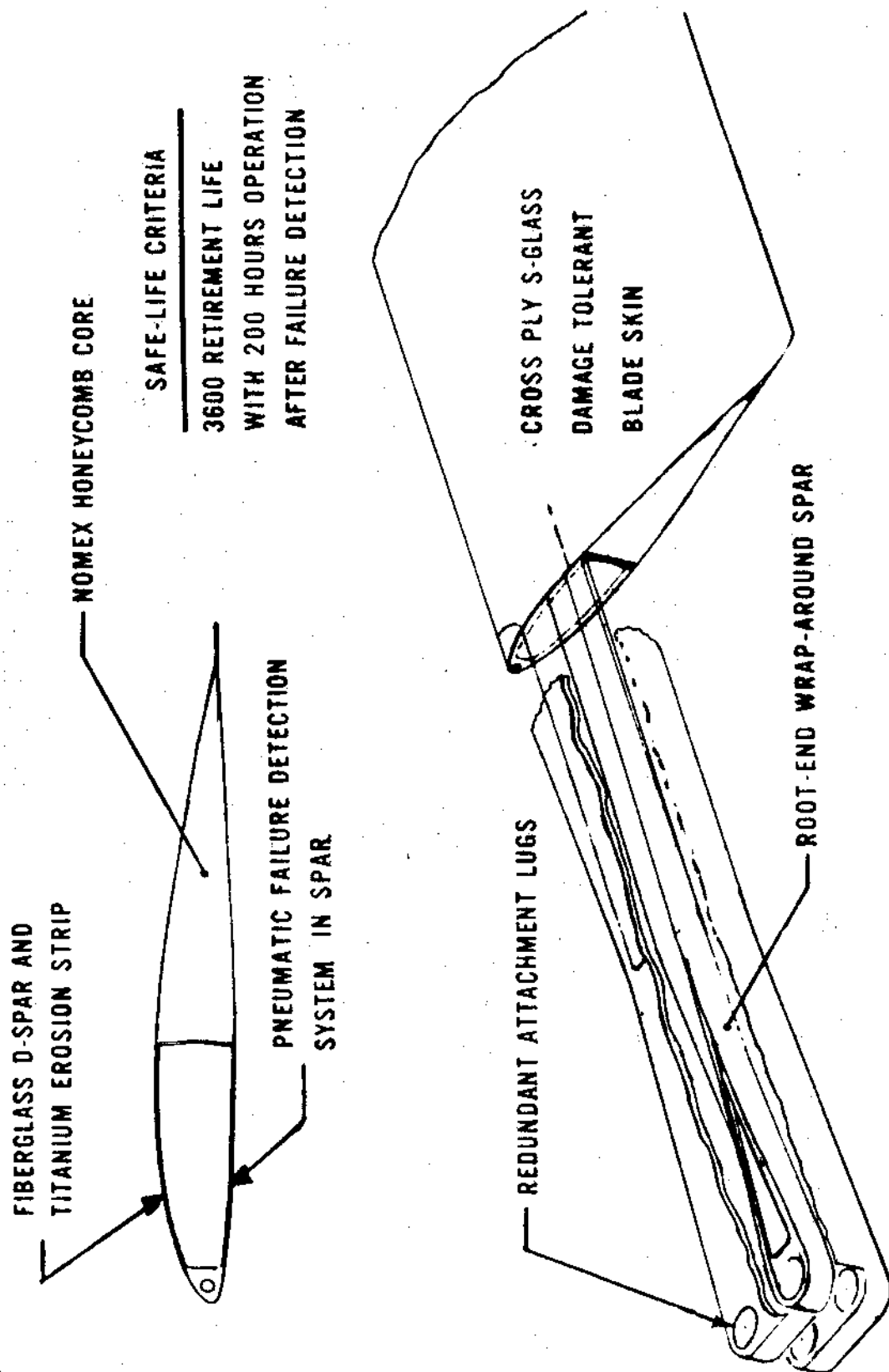


# HLH ELASTOMERIC BEARING



**FIGURE 3A**

## HLH ROTOR BLADE CONSTRUCTION



**FIGURE 4**

# MATCHED DIE BLADE CURING

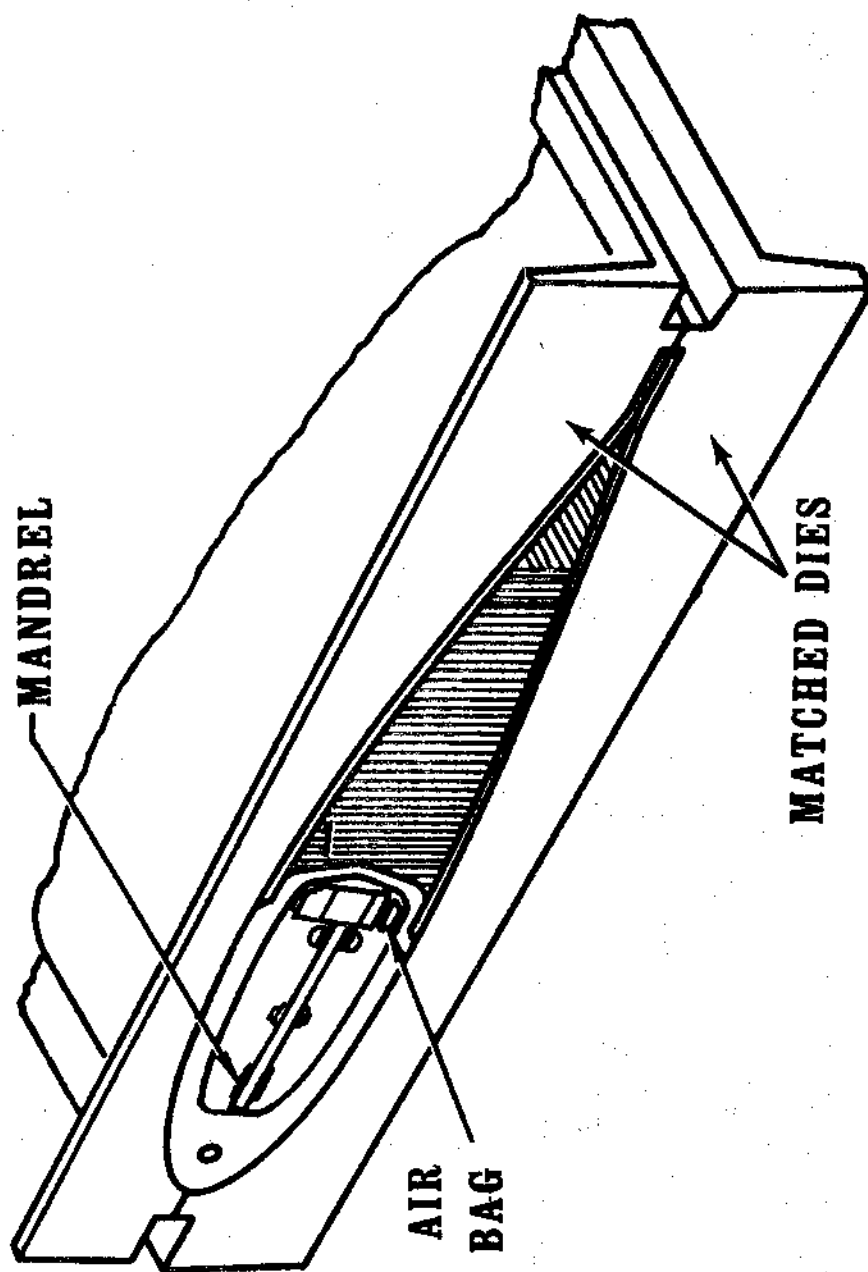
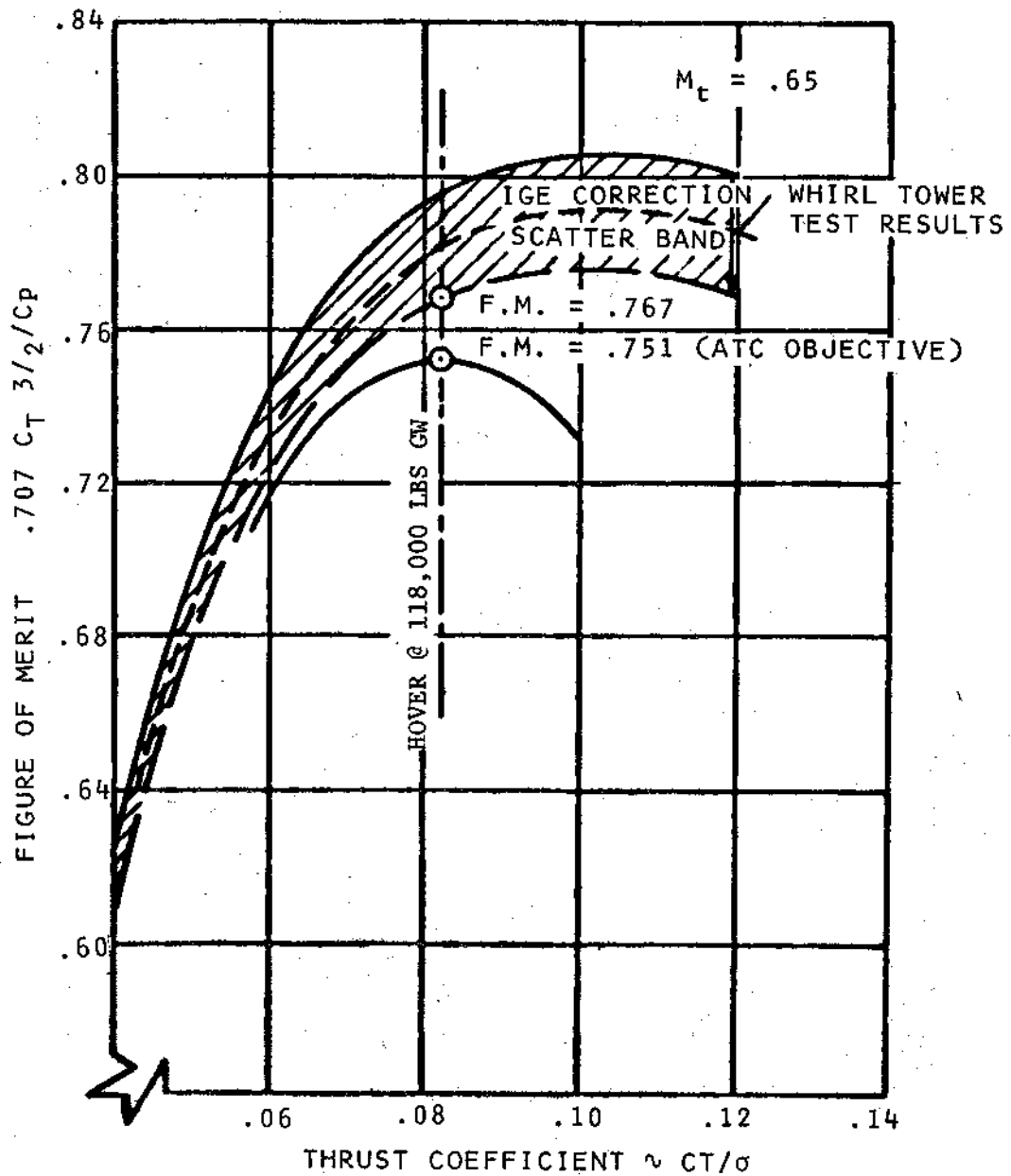


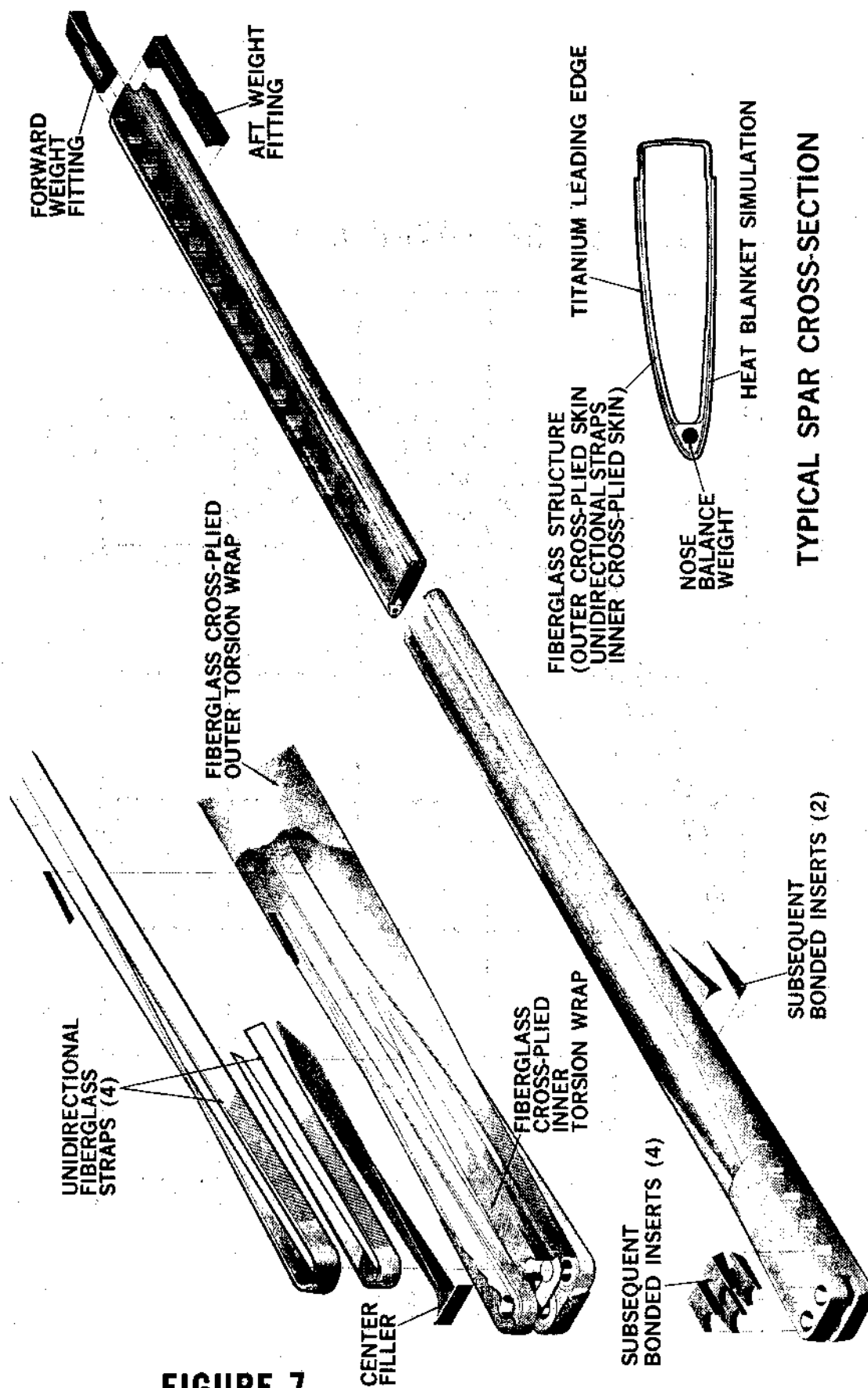
FIGURE 5

## HLH ROTOR HOVER EFFICIENCY

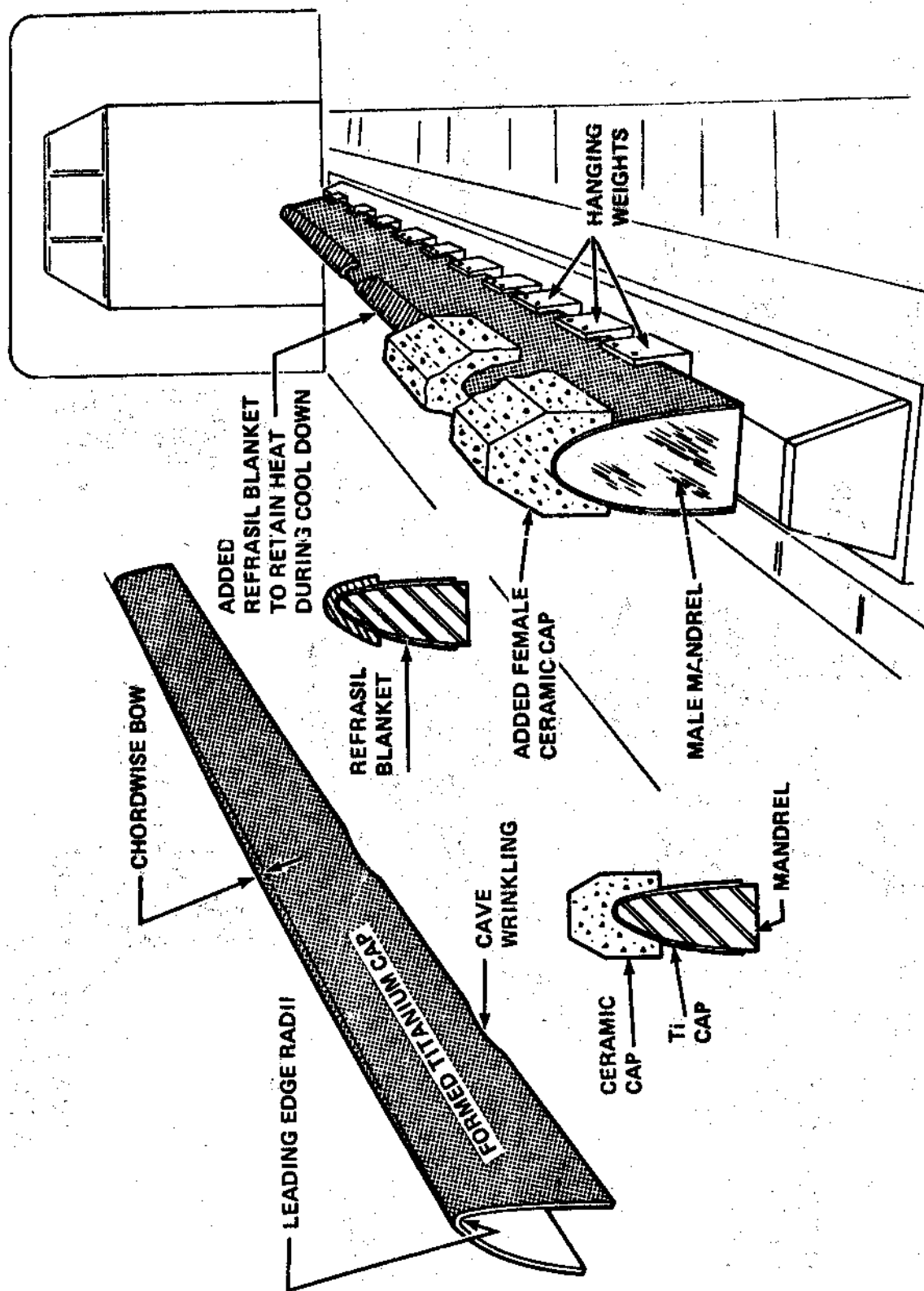


**FIGURE 6**

# HLH SPAR ASSEMBLY



**FIGURE 7**



*Tooling Improvements for Titanium Nosecap*

**FIGURE 8**

## UPPER CONTROLS

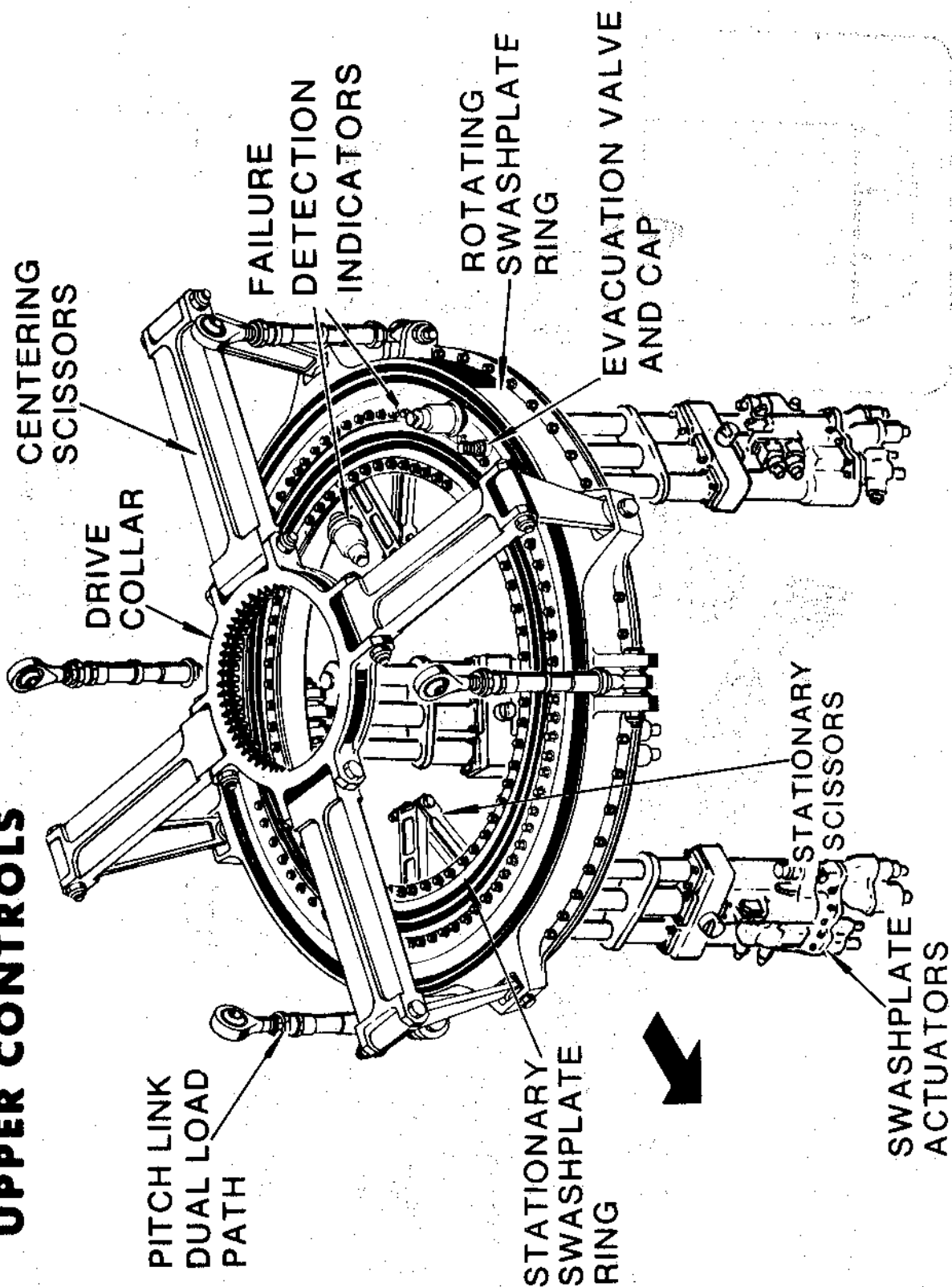


FIGURE 9

# HLH SWASHPLATE

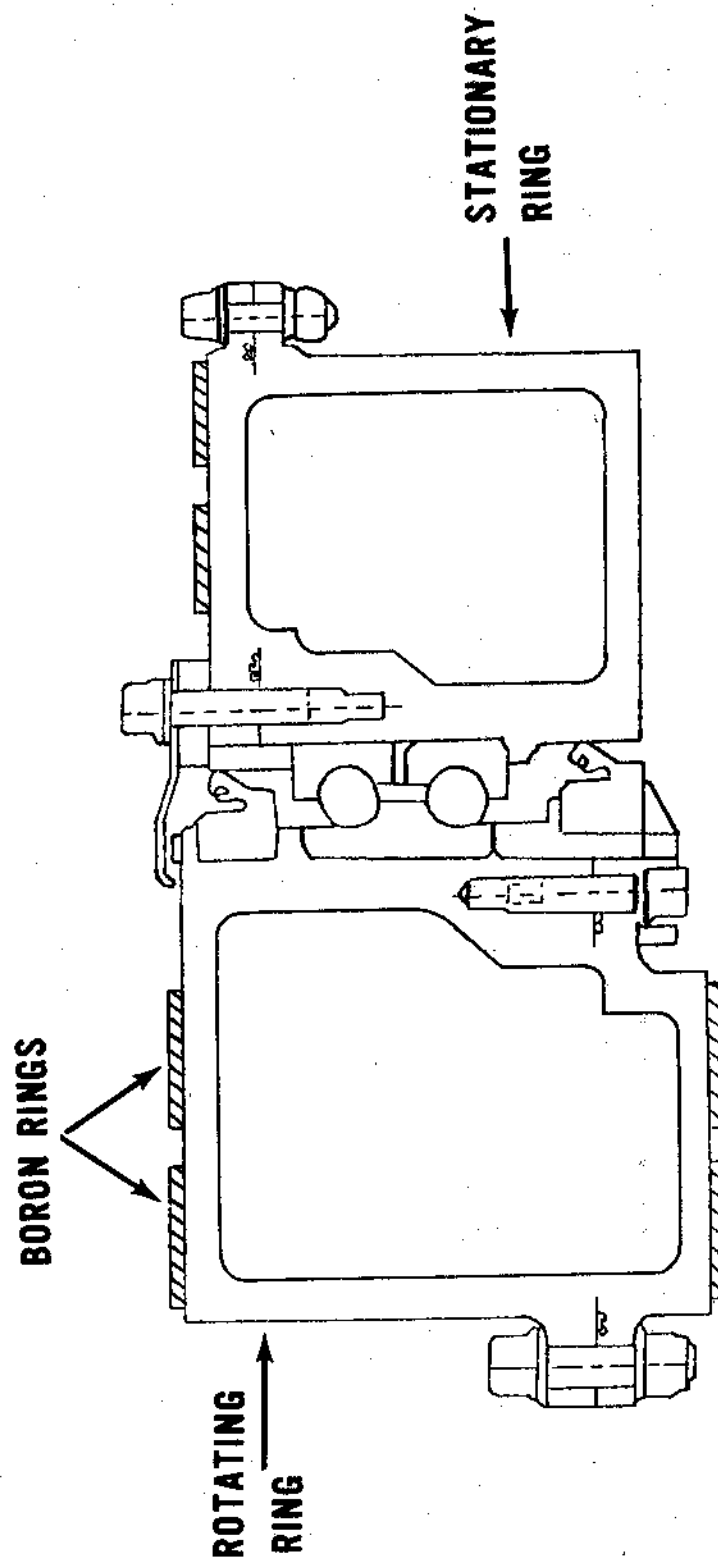


FIGURE 10

B. DRIVE SYSTEM

## B. DRIVE SYSTEM

### PAST TECHNOLOGY ACCOMPLISHMENTS - DRIVE SYSTEM

#### USE OF VASCO X-2 STEEL GEARS - MARCH 1972

DESIGNED AND DEVELOPED GEARS MADE OF VASCO X-2 HIGH HOT HARDNESS STEEL TO CAPITALIZE ON IMPROVED SCUFFING RESISTANCE INHERENT IN THIS MATERIAL. THIS FEATURE ALLOWS THE DESIGN OF LIGHTER AND LONGER LASTING GEARS THAN CONVENTIONAL MATERIALS WOULD ALLOW. A GEAR WEIGHT INCREASE OF 20 PERCENT WOULD HAVE BEEN REQUIRED WITHOUT THIS DEVELOPMENT.

BOEING VERTOL DOCUMENT NO. - D301-10036-2 DATED AUGUST 1974

#### ADVANCED TRANSMISSION HOUSING MATERIAL DEVELOPMENT - NOVEMBER 1972

THE HLH PROGRAM DEVELOPED THE MANUFACTURING TECHNOLOGY TO SUCCESSFULLY POUR LARGE CASTINGS OF ZE41 MAGNESIUM ALLOY, FIGURE 11. BECAUSE OF ITS IMPROVED STRENGTH PROPERTIES, THIS MATERIAL PERMITS DESIGN OF 10 PERCENT LIGHTER CASTINGS THAN POSSIBLE WITH EXISTING MATERIALS.

BOEING VERTOL DOCUMENT NO. - D301-10147-1 DATED NOVEMBER 1972

#### INTEGRAL AND REDUNDANT LUBRICATION SYSTEM - NOVEMBER 1972

DESIGNED AND DEVELOPED HELICOPTER TRANSMISSIONS WITH SELF-CONTAINED AND REDUNDANT LUBRICATION SYSTEM. THIS ELIMINATES ALL EXTERNAL OIL LINES WHICH ADD WEIGHT AND COMPLEXITY, FIGURE 12, THUS IMPROVING RELIABILITY, MAINTAINABILITY, AND SURVIVABILITY.

BOEING VERTOL DOCUMENT NO. - D301-10203-1 DATED APRIL 1973

## B. DRIVE SYSTEM (CONTINUED)

### INTEGRAL TRANSMISSION OIL COOLING SYSTEMS - NOVEMBER 1972

DESIGNED AND DEVELOPED TRANSMISSION OIL COOLING SYSTEMS TO BE AN INTEGRAL PART OF THE TRANSMISSION ASSEMBLY. THIS ELIMINATES THE NEED FOR EXTERNAL OIL LINES, AND AN EXTERNAL POWER SOURCE, FIGURE 12. SURVIVABILITY, MAINTAINABILITY, AND RELIABILITY ARE GREATLY IMPROVED AT LOWER WEIGHT THAN WITH EXISTING CONCEPTS. BOEING VERTOL DOCUMENT NO. - D301-10203-1 DATED APRIL 1973

### HIGH SPEED GREASED SHAFT BEARINGS - MAY 1973

THE HLH PROGRAM DEVELOPED GREASE LUBRICATED BEARINGS FOR 11,500 RPM HELICOPTER ENGINE SHAFT AND 8,000 RPM SYNC SHAFT SUPPORT BEARINGS, FIGURE 13. FOR CONVENTIONAL BEARINGS TO HAVE OPERATED UNDER THESE CONDITIONS OIL LUBRICATION SYSTEMS WOULD HAVE BEEN REQUIRED WHICH WOULD HAVE ADDED HEAVY, COMPLEX, AND VULNERABLE OIL FEED SYSTEMS AT NUMEROUS LOCATIONS ALONG THE DRIVE SHAFTING. AS A COROLLARY DEVELOPMENT, MAINTAINABILITY OF GREASE LUBRICATED BEARINGS WAS IMPROVED OVER SMALLER EXISTING HELICOPTERS.

US ARMY DOCUMENT NO. - USAAMRDL-TR-74-33 DATED JUNE 1974

### HIGH SPEED TAPERED ROLLER BEARINGS - MAY 1973

DESIGNED AND DEVELOPED HIGH SPEED TAPERED ROLLER BEARINGS FOR HELICOPTER TRANSMISSIONS. THESE BEARINGS, FIGURE 14, BECAUSE OF THEIR INHERENT HIGHER LOAD CARRYING CAPABILITIES PERMIT LIGHTER, MORE RELIABLE, AND LESS COMPLEX TRANSMISSIONS THAN CURRENT TECHNOLOGY.

US ARMY DOCUMENT NO. - USAAMRDL-TR-74-33 DATED JUNE 1974

## B. DRIVE SYSTEM (CONTINUED)

### MANUFACTURING TECHNOLOGY TO BUILD GEARS OF VASCO X-2 - OCTOBER 1973

UNDER THE HLH PROGRAM MANUFACTURING TECHNOLOGY FOR MAKING GEARS OF VASCO X-2 WAS DEVELOPED. THIS CAPABILITY APPLIES TO A BROAD RANGE OF GEAR SIZES AND MAKES MANY NEW DEVELOPMENTS POSSIBLE. COSTS, MANUFACTURING PROCESSES, AND LEAD TIMES CAN NOW BE ACCURATELY PREDICTED PRIOR TO INITIATION OF ANY NEW PROGRAM.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

### GRAPHITE DISC FOR ROTOR BRAKE - NOVEMBER 1973

DESIGNED, DEVELOPED, AND QUALIFIED A HELICOPTER ROTOR BRAKE DISC, FIGURES 15 AND 16, OF GRAPHITE MATERIAL AT SIGNIFICANT SAVINGS IN WEIGHT AND COST PER STOP. IMPROVEMENTS WERE MADE IN GRAPHITE DISC FABRICATION WHICH PERMITTED DISCS TO BE MADE THICKER THAN HAD BEEN PREVIOUSLY THOUGHT POSSIBLE. THIS PERMITTED THE HLH TO ACHIEVE THE HIGHEST EXISTING ENERGY ABSORBING CAPABILITY, AND TO EXCEED THE MINIMUM REQUIREMENT FOR DESIGN LIFE. DEMONSTRATED WERE 250 ROTOR STOP CYCLES WITH AN ESTIMATED REMAINING CAPABILITY TO REACH 825 STOPS.

BOEING VERTOL DOCUMENT NO. - D301-10214-1 DATED JUNE 1973

### STATIC AND DYNAMIC INSTRUMENTATION SYSTEMS FOR MEASURING AND TELEMETERING

#### GEAR TOOTH ROOT STRESSES - FEBRUARY 1974

AN ENTIRELY NEW CONCEPT IN GEAR INSTRUMENTATION WAS DEVELOPED IN WHICH STRESSES WERE ACTUALLY MEASURED IN GEAR TEETH ROOT FILLETS UNDER DYNAMIC CONDITIONS AND AT FULL OPERATING LOADS AND SPEEDS. TELEMETERING WAS ALSO DEVELOPED AS A COMPANION TO THIS TO REPLACE CONVENTIONAL SLIP RING CONCEPTS, FIGURE 17. USE

B. DRIVE SYSTEM (CONTINUED)

OF THIS CONCEPT TO INSTRUMENT AND TEST TRANSMISSION GEARS WILL VASTLY IMPROVE DESIGN AND TEST CAPABILITIES RESULTING IN GREATER CONFIDENCE IN TEST STAND RESULTS PRIOR TO ACTUAL FLIGHT TESTING OF THE AIRCRAFT.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

FULL FLOW METALLIC ELEMENT DETECTION SYSTEM - APRIL 1974

THE HLH PROGRAM HAS DEVELOPED A SYSTEM TO INDICATE METALLIC ELEMENTS IN OIL FLOW WHICH WILL MONITOR ALL OIL FLOWING TO BEARINGS AND GEARS. THIS WAS ACHIEVED THROUGH USE OF NEWLY DEVELOPED INDICATING SCREENS WHICH ARE INSTALLED AT THE OIL FLOW SOURCE, FIGURE 18. ALL OIL IS CONTINUOUSLY MONITORED PROVIDING GREATER PROBABILITY OF DETECTING WEAR OR CHIP PARTICLES BEFORE A FAILURE CAN OCCUR. THIS IS A MAJOR ADVANCEMENT OVER EXISTING SYSTEMS WHICH CAN ONLY DETECT THOSE ELEMENTS WHICH REACH THE SUMP BOTTOM.

BOEING VERTOL DOCUMENT NO. - D301-10203-1 DATED APRIL 1973

ANALYSIS AND TEST SUBSTANTIATION OF GEAR MASS DAMPING RATIO REQUIREMENTS - JULY 1974

ANALYTICAL PROGRAMS WERE DEVELOPED TO PERMIT DAMPING REQUIREMENTS TO BE DETERMINED FROM DESIGN PARAMETERS, FIGURE 19. THIS ELIMINATES THE UNCERTAINTY OF WAITING FOR TEST RESULTS TO REVEAL THE PRESENCE OF DESTRUCTIVE RESONANCES. INABILITY TO PREDICT THESE RESONANCES OR TO ACCURATELY DESIGN GEAR DAMPING LEADS TO COSTLY AND TIME CONSUMING TEST DELAYS. CURRENTLY, STATE-OF-THE-ART RULES OF THUMB AND PAST EXPERIENCE ARE UTILIZED TO DETERMINE SIZE OF GEAR DAMPING RINGS REQUIRED TO PRECLUDE RESONANCES.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

B. DRIVE SYSTEM (CONTINUED)

ANALYTIC PREDICTION OF GEAR STRESSES AND VERIFICATION BY TEST - SEPTEMBER 1974

GEAR STRESSES ARE CONVENTIONALLY PREDICTED BY GROSS STRESS ANALYSES ON WHOLE GEARS AND EVALUATION OF PATTERNS BY VISUAL MEANS. IMPROVED ANALYTIC TECHNIQUES WERE DEVELOPED TO MORE ACCURATELY PREDICT GEAR STRESSES AT SPECIFIC POINTS ON THE GEAR FACE. TESTING TECHNIQUES TO VERIFY THESE CALCULATIONS ACCOMPANIED THIS TO THE POINT THAT SPIRAL BEVEL GEAR PATTERNS COULD BE OPTIMIZED. UTILIZING THIS WILL YIELD GREATER LOAD CARRYING CAPACITIES AT LIGHTER WEIGHTS BY ELIMINATING THE NEED FOR SOME DESIGN CONSERVATISM.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

## B. DRIVE SYSTEM (CONTINUED)

### FUTURE TECHNOLOGY GOALS - DRIVE SYSTEM

#### HLH AFT AND COMBINING TRANSMISSIONS - DECEMBER 1974

AN INTERMEDIATE GOAL OF DEMONSTRATING TRANSMISSION DESIGN CAPABILITIES WILL BE ACCOMPLISHED BY RUNNING AT APPROXIMATELY 60 PERCENT OF FULL DESIGN LOADS, FIGURES 12 AND 17. THIS DEMONSTRATION WILL VERIFY LUBRICATION SYSTEM DESIGN, BEARING WEAR RESISTANCE, GEAR SCUFFING RESISTANCE, AND GENERAL SYSTEM DYNAMICS. BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

#### INTEGRATED DYNAMIC SYSTEM TEST - JANUARY 1975

INTEGRATED DYNAMIC SYSTEM SUBSTANTIATION CONFIRMATION OF THE HLH DYNAMIC SYSTEM REQUIRES THAT ESSENTIAL POWER TRAIN COMPONENTS (AFT ROTOR TRANSMISSION, COMBINING TRANSMISSION, AFT ROTOR SYSTEM, ENGINES, AND CONNECTING SHAFTS) BE DEMONSTRATED UNDER INTEGRATED CONDITIONS SIMILAR TO THE FLIGHT ENVIRONMENT. THIS PROVIDES SYSTEM INTEGRATION VERIFICATION OF ALL COMPONENTS WHICH WOULD NOT BE POSSIBLE BY INDIVIDUAL TESTS, FIGURE 20. ROTOR DOWNWASH VELOCITIES WILL BE MEASURED AND EVALUATED WHICH COULD NOT BE ACCOMPLISHED THROUGH ANY OTHER MEANS.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

#### DEVELOP THE SIREN TEST AS A HIGH ENERGY VIBRATION SOURCE FOR EXCITATION OF LARGE GEARS - MAY 1975

WITH THIS SOURCE PERFECTED WE WILL HAVE THE CAPABILITY TO MEASURE RESONANT STRESS LEVELS IN LARGE GEARS PRIOR TO FULL-SCALE TESTING. SIREN TESTING RESULTS ARE AVAILABLE. REMAINING TO BE DONE IS THE CONFIRMATION THROUGH BENCH TESTS OF FULL-SCALE TRANSMISSIONS AT 100 PERCENT LOAD AND SPEED. THIS WILL BE FULLY DEVELOPED IN MAY-AUGUST 1975.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

B. DRIVE SYSTEM (CONTINUED)

ANALYSIS AND TEST CORRELATION TECHNIQUES OF GEAR NATURAL FREQUENCIES WILL BE DEVELOPED - AUGUST 1975

WITH THIS DESIGN TOOL WE CAN PREDICT GEAR NATURAL FREQUENCIES AND DESIGN GEARS SO THAT DESTRUCTIVE RESONANCES WILL NOT OCCUR. YET TO BE DONE IS THE CONFIRMATION OF ANALYTIC PROGRAMS THROUGH TESTS. THIS WILL BE ACHIEVED IN AUGUST 1975 WHEN FULL LOAD BENCH TESTING IS CONDUCTED.

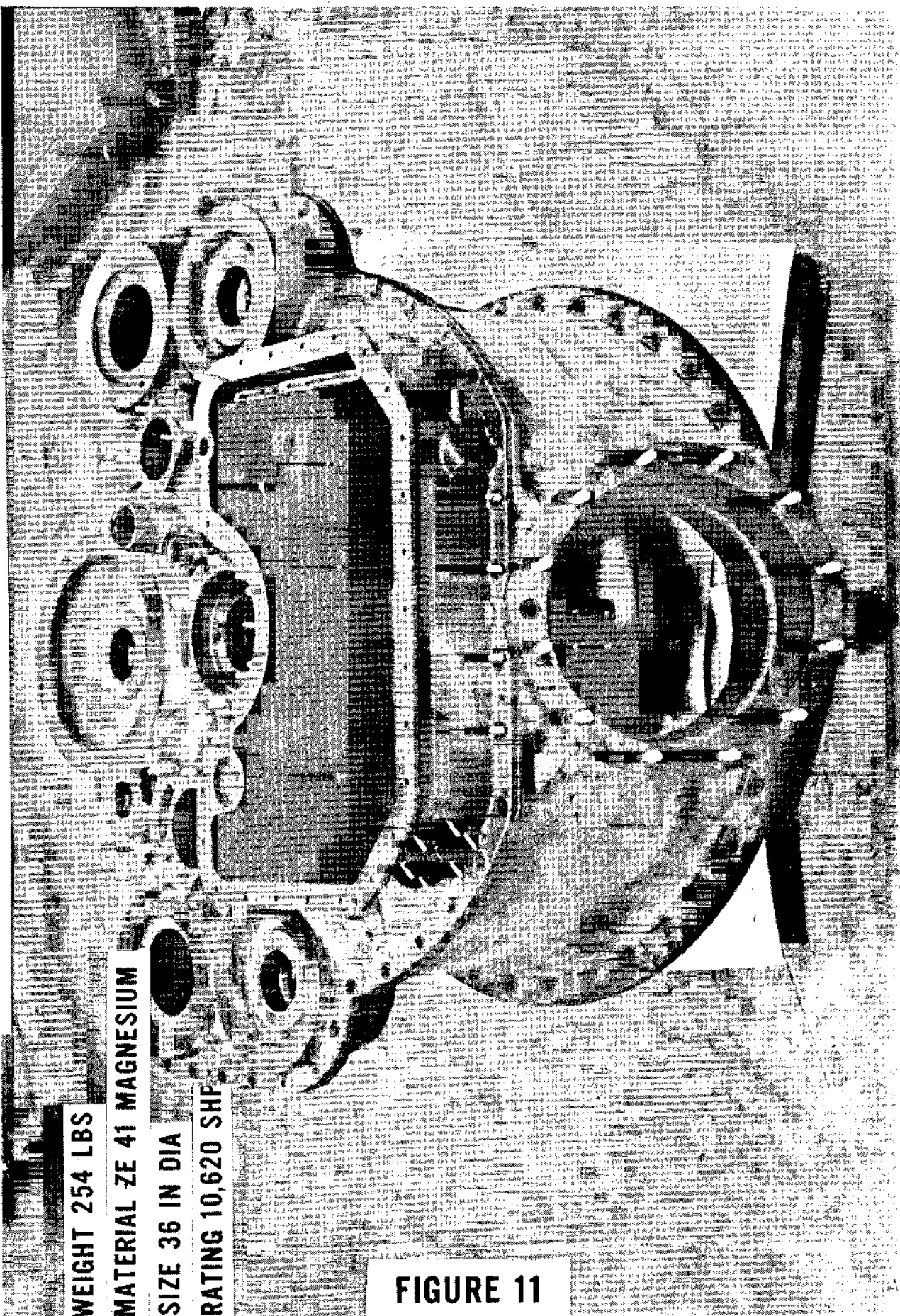
BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

DIAGNOSTIC AND PROGNOSTIC FAILURE DETECTION SYSTEM - MARCH-OCTOBER 1976

A DIAGNOSTIC AND PROGNOSTIC FAILURE DETECTION SYSTEM BASED UPON SPECTRAL ANALYSIS OF VERY HIGH FREQUENCY (250 H<sub>z</sub>) VIBRO/ACOUSTIC ENERGY IS BEING DEVELOPED AND WILL BE EVALUATED. THIS WILL PROVIDE A WARNING OF THE START OF FATIGUE FAILURE OR OTHER DEFECTS BEFORE STRUCTURAL WEAKENING CAN CAUSE MAJOR CATASTROPHIC FAILURE. THIS SYSTEM WILL GREATLY ENHANCE TRANSMISSION TEST CAPABILITY BY REDUCING DOWNTIME DUE TO TEST FAILURES. FUTURE APPLICATION TO ALL HELICOPTERS WILL REDUCE FATALITIES. THIS WILL BE ACHIEVED IN MARCH-OCTOBER 1976 DURING PROTOTYPE FLIGHT TEST.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

# AFT TRANSMISSION HOUSING



WEIGHT 254 LBS

MATERIAL ZE 41 MAGNESIUM

SIZE 36 IN DIA

RATING 10,620 SHP

FIGURE 11

# AFT TRANSMISSION

WEIGHT 3260.1 LBS  
RATING 10,620 SHP

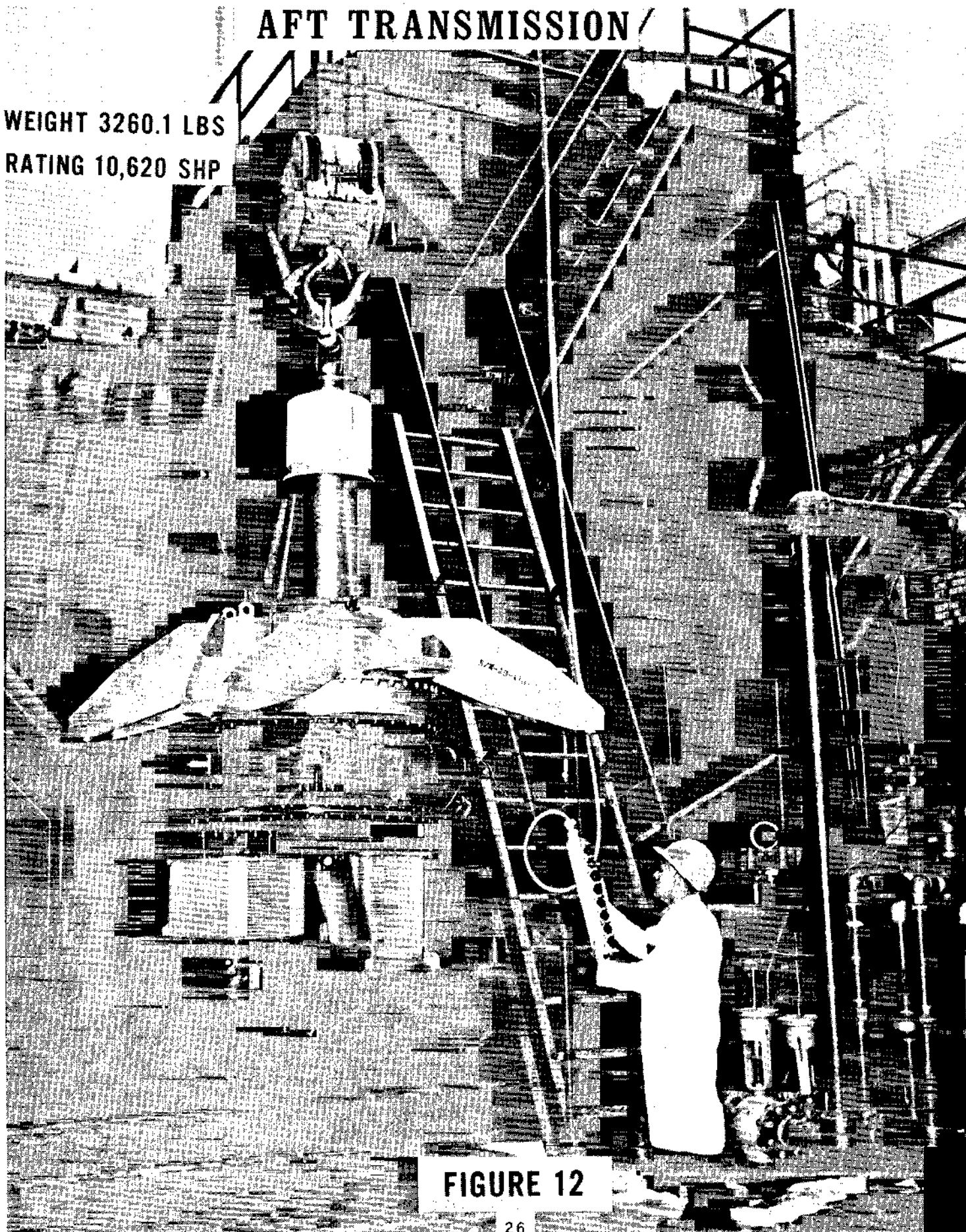


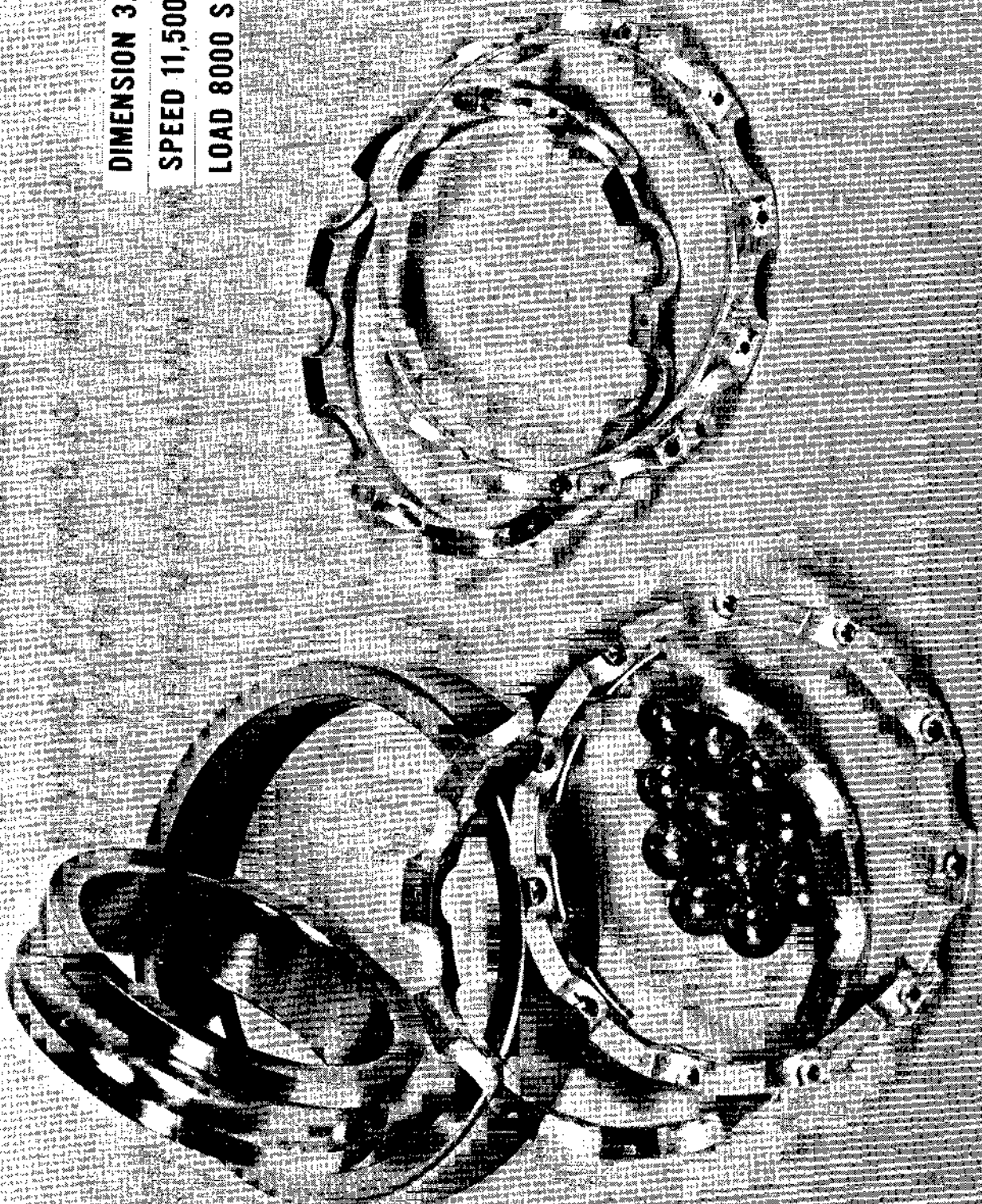
FIGURE 12

# GREASE LUBRICATED SHAFT BEARINGS

**DIMENSION 3.54 IN DIA**

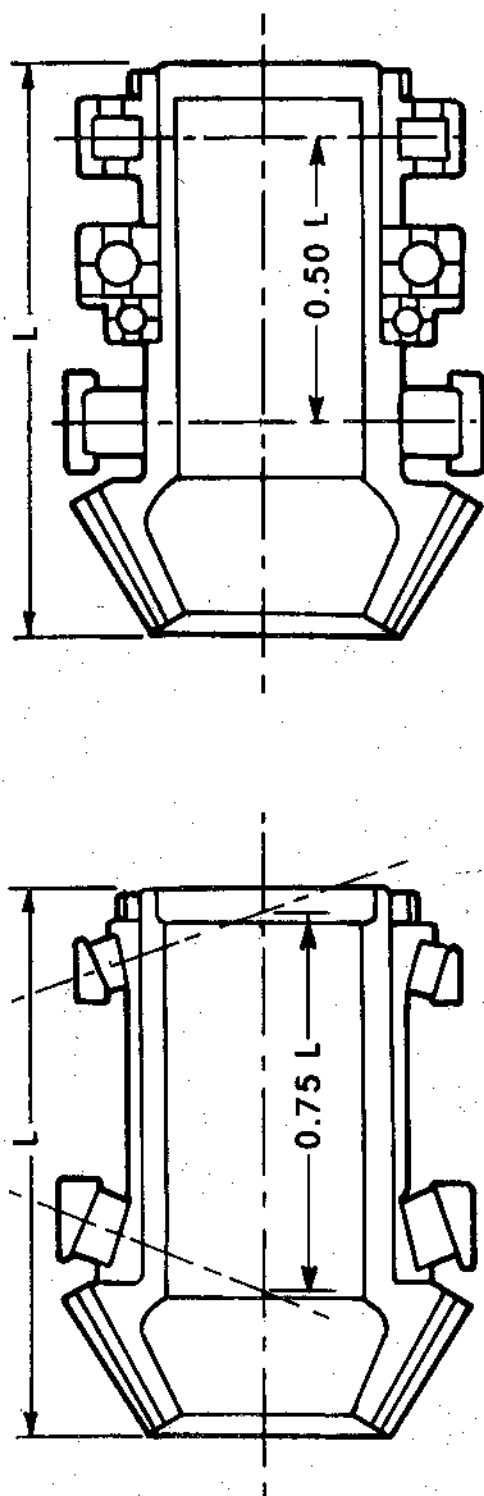
**SPEED 11,500 RPM**

**LOAD 8000 SHP**



**FIGURE 13**

## HIGH-SPEED TAPERED ROLLER BEARINGS



HLH TAPER BEARING

CONVENTIONAL  
BALL/ROLLER BEARINGS

### HLH ADVANTAGES

- REDUCED BEARING WEIGHT (APPROX 40% )
- GREATER RELIABILITY  
(2 BEARINGS COMPARED TO 4 BEARINGS)
- MORE RIGID GEAR MOUNTING

FIGURE 14

# COMBINER TRANSMISSION

OUTPUT TO AFT TRANSMISSION

GRAPHITE COMPOSITE

ROTOR BRAKE

THREE ENGINE INPUTS

FIGURE 15

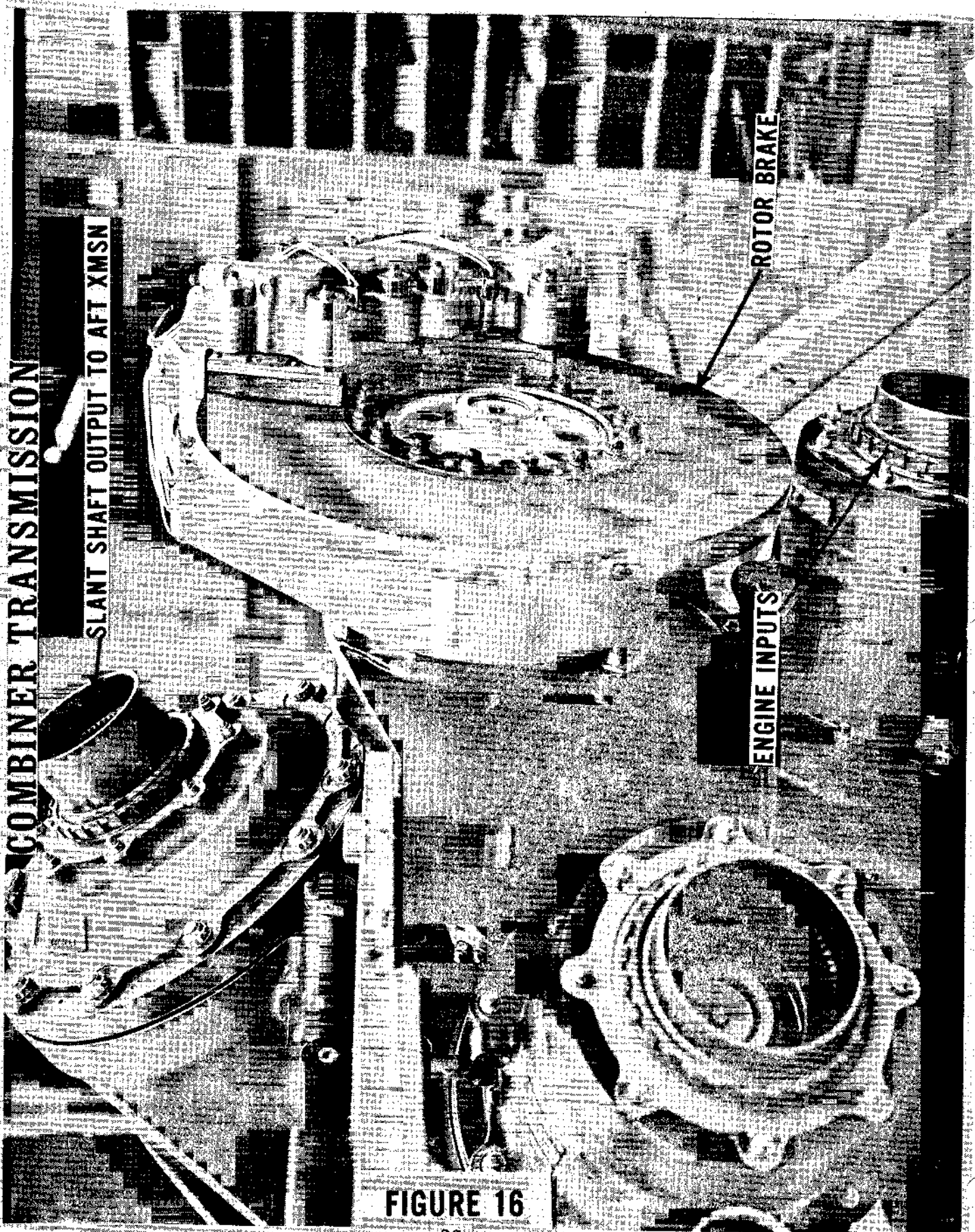
COMBINER TRANSMISSION

SLANT SHAFT OUTPUT TO AFT XMSN

ROTOR BRAKE

ENGINE INPUTS

FIGURE 16



# COMBINER TRANSMISSION

OUTPUT TO  
AFT TRANSMISSION

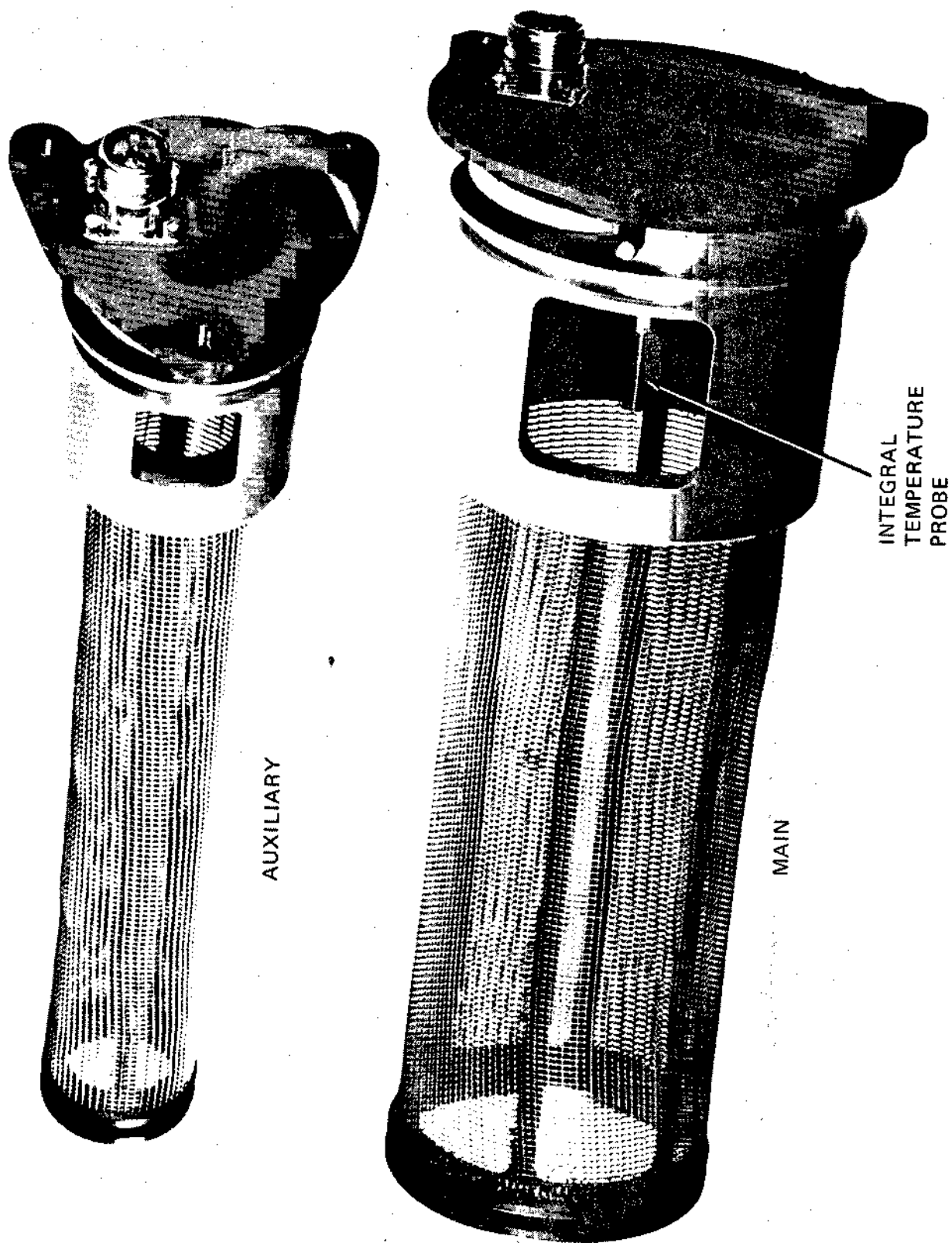
ENGINE INPUTS

OUTPUT TO  
FWD TRANSMISSION

OIL COOLER

OIL SUMP

FIGURE 17



Main and Auxiliary Indicating Screens for Heavy-Lift Helicopter Transmission

FIGURE 18

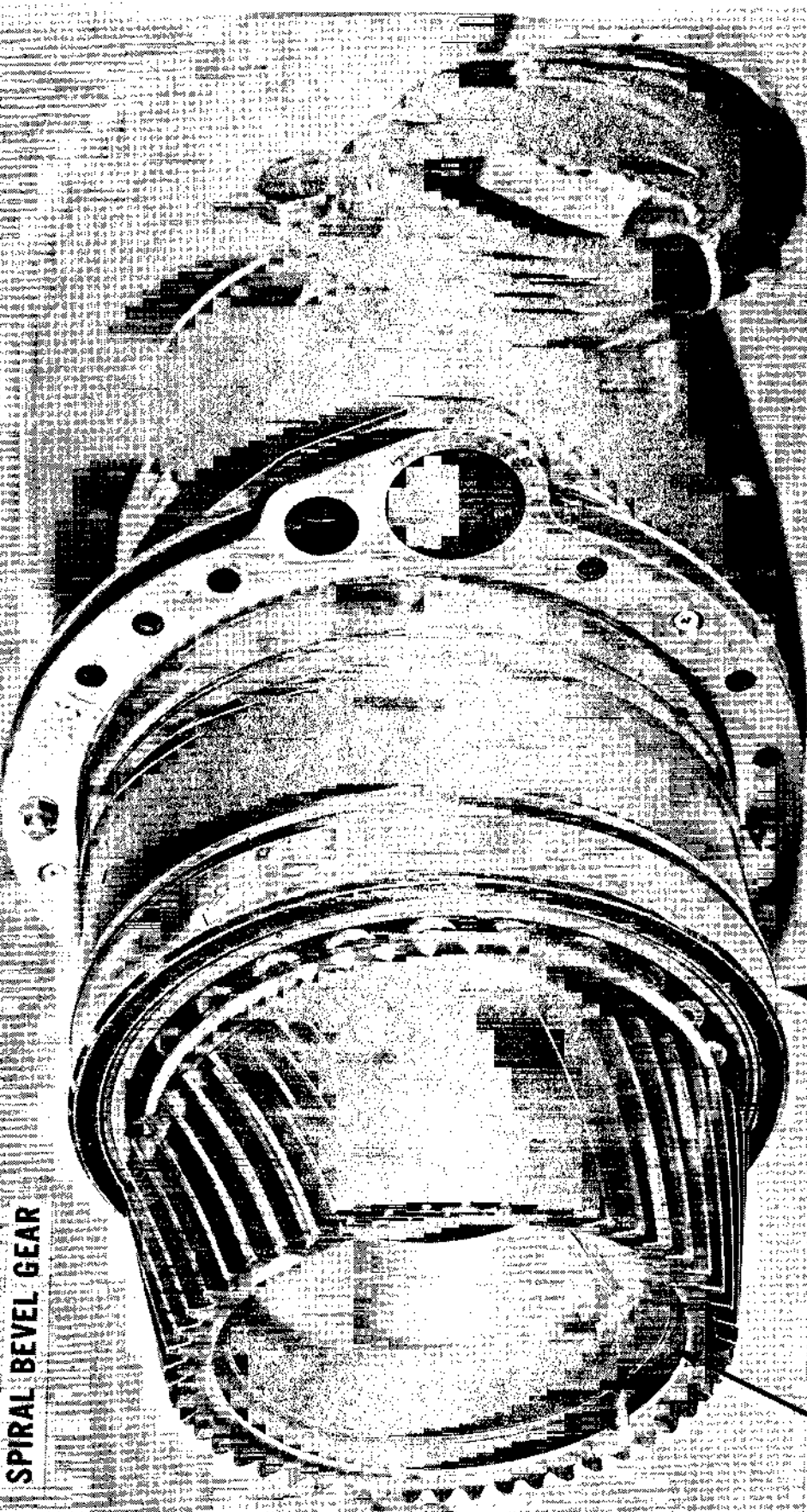
# COMBINER GEAR BOX (INPUT PINION)

SPIRAL BEVEL GEAR

HIGH SPEED  
TAPERED ROLLER  
BEARINGS

DAMPING RING

FIGURE 19



# DYNAMIC SYSTEM TEST RIG

AFT DYNAMIC SYSTEM

M-62B ENGINES (3 EA)

COMBINER GEAR BOX

WATER BRAKE  
(FWD ROTOR)

FIGURE 20

C. FLIGHT CONTROL SYSTEM

### C. FLIGHT CONTROL SYSTEM

#### PAST TECHNOLOGY ACCOMPLISHMENTS - FLIGHT CONTROL SYSTEM

##### FIRST ROTARY WING FLY-BY-WIRE DEMONSTRATION - JULY-SEPTEMBER 1973

THE FIRST HELICOPTER TO BE FLOWN WITH A FLY-BY-WIRE CONTROL SYSTEM (WITH NO MECHANICAL BACKUP) WAS THE BOEING MODEL 347 HLH FLIGHT CONTROLS FEASIBILITY DEMONSTRATION AIRCRAFT. THE TESTING PROCEEDED EXPEDITIOUSLY WITH ONLY MINOR FUNCTIONAL PROBLEMS ENCOUNTERED DURING GROUND CHECKOUT. THE FLIGHT TESTING WAS ACCOMPLISHED WITH NO IN-FLIGHT MALFUNCTIONS OR FAILURES. PERFECT PERFORMANCE OF THE FLY-BY-WIRE SYSTEM HAS CONTINUED IN SUPPORT OF THE AUTOMATIC FLIGHT CONTROL SYSTEM EVALUATION WITH A TOTAL ACCRUED FLIGHT TIME OF APPROXIMATELY 315 HOURS. THE PERFORMANCE OF THE SYSTEM HAS PROVEN THE FEASIBILITY OF FLY-BY-WIRE IN ROTARY WING AIRCRAFT AND DEMONSTRATES THAT THE INTRINSIC ADVANTAGE OF THE FLY-BY-WIRE CAN BE REALIZED, NAMELY INCREASED SURVIVABILITY AND FLIGHT SAFETY. FIGURES 21-24 DEPICT THE MODEL 347 FLIGHT VEHICLE AND THE FLY-BY-WIRE SYSTEM DESCRIPTION.

BOEING VERTOL DOCUMENT NO. - D301-10198-2 DATED DECEMBER 1973

##### AUTOMATIC BUILT-IN TEST AND FAILURE DETECTION CAPABILITY - JULY-SEPTEMBER 1973

AUTOMATIC BUILT-IN TEST AND FAILURE DETECTION CAPABILITY HAS BEEN DEMONSTRATED FOR APPROXIMATELY 250 HOURS OF FLIGHT TESTING AND APPROXIMATELY 1,500 HOURS OF INTEGRATED RIG BENCH TESTING. IN NO CASE HAS THE FAILURE DETECTION CAPABILITY NOT INDICATED THE PRESENCE OF A REAL FAILURE. FIGURES 25-27 SHOW THE SYSTEM EQUIPMENT.

BOEING VERTOL DOCUMENT NO. - D301-10198-2 DATED DECEMBER 1973

C. FLIGHT CONTROL SYSTEM (CONTINUED)

AUTOMATIC FLIGHT CONTROL SYSTEM INTERFACE - JULY-SEPTEMBER 1973

THE DESIGN OF DIRECT ELECTRICAL LINKAGE SYSTEM (DELS) FLIGHT SAFETY PROTECTION AGAINST AUTOMATIC FLIGHT CONTROL SYSTEM HARD-OVER FAILURES HAS BEEN DEMONSTRATED. SIMULATED AUTOMATIC FLIGHT CONTROL SYSTEM SINGLE- AND MULTI-AXIS FAILURES WERE INDUCED DURING THE FLY-BY-WIRE TESTING. PERFORMANCE OF THE INTERFACE CIRCUITS WAS CORRECT IN ALL RESPECTS. THE MECHANIZATION OF THIS PERFORMANCE IS EXHIBITED BY MEDIAN VALUE SELECTION FROM THREE INPUT SIGNALS, DISCRIMINATION AND REJECTION WHEN ONE INPUT DISAGREES, AND PROVISION OF AUTHORITY AND RATE LIMITING IN THE EVENT OF A SIMULTANEOUS HARD-OVER INPUT. BOEING VERTOL DOCUMENT NO. - D301-10198-2 DATED DECEMBER 1973

INNOVATIVE DELS REDUNDANCY MANAGEMENT CONCEPTS - JULY-SEPTEMBER 1973

THE THREE-CHANNEL DELS IS MECHANIZED AS A TWO FAIL-OPERATIVE SYSTEM. THIS MEANS FLIGHT CONTROL OF THE AIRCRAFT CAN BE MAINTAINED AFTER THE LOSS OF TWO OUT OF THREE CHANNELS. AUTOMATIC TRANSIENT FREE TRANSFER FROM A FAILED CHANNEL TO AN OPERATIVE CHANNEL HAS BEEN ACHIEVED AND WAS EXHIBITED WHEN HARD-OVER DELS CHANNEL FAILURES WERE SIMULATED IN FLIGHT WHEREIN THE AIRCRAFT RESULTING DISTURBANCE WAS IMPERCEPTIBLE TO THE PILOT. EACH OF THE THREE DELS CHANNELS IS MECHANIZED WITH IN-LINE MONITORING WHEREIN INDIVIDUAL CHANNEL SIGNALS ARE MONITORED INTERNALLY FOR AUTOMATIC FAILURE DETECTION AND CHANNEL SHUTDOWN. UPON SHUTDOWN, CONTROL IS AUTOMATICALLY TRANSFERRED WITH NO CONTROL TRANSIENT TO AN OPERATIVE CHANNEL. MULTIPLE CHANNEL FAILURES FROM CASCADING FAILURE EFFECTS ARE PRECLUDED.

BOEING VERTOL DOCUMENT NO. - D301-10198-2 DATED DECEMBER 1973.

### C. FLIGHT CONTROL SYSTEM (CONTINUED)

#### IMPROVED STABILITY AND CONTROL HANDLING QUALITIES - MARCH-JUNE 1974

A STABILITY AND CONTROL CONCEPT HAS BEEN DEMONSTRATED AND EVALUATED BY THE ARMY UTILIZING A LINEAR VELOCITY DEMAND. INERTIAL REFERENCE UNITS PROVIDE LONGITUDINAL AND LATERAL GROUND SPEED VELOCITY SIGNALS BELOW 45 KNOTS AIRSPEED WHILE STANDARD AIR DATA SENSORS PROVIDE VELOCITY FEEDBACK ABOVE 45 KNOTS. THE UTILIZATION OF GROUND SPEED HAS BEEN PROVEN EFFECTIVE FOR BOTH LOW SPEED AND HOVER HANDLING QUALITIES. A TRANSIENT-FREE GROUND SPEED/AIRSPEED SWITCH HAS BEEN DEMONSTRATED FOR THE PURPOSE OF OVERCOMING THE EFFECT OF WINDS WHEN TRANSITIONING THROUGH THE 45-KNOT GROUND SPEED/AIRSPEED INTERFACE. FIGURE 28 CONTAINS A TABLE OUTLINING THE VARIOUS CONTROL AXES HANDLING QUALITIES WHILE FIGURE 29 DESCRIBES SOME OF THE AUTOMATIC CONTROL MODES.

BOEING VERTOL DOCUMENT NO. - D301-10208-2 DATED DECEMBER 1974

#### FOUR-AXIS LOAD CONTROLLING CREWMAN CONTROLLER DEMONSTRATION - MAY 1974

A FOUR-AXIS SIDEARM CONTROLLER UTILIZED IN THE LOAD CONTROLLING CREWMAN STATION HAS PROVEN TO BE MOST EFFECTIVE FOR THE ACCOMPLISHMENT OF PRECISION MANEUVERING AND HOVER EXTERNAL LOAD HANDLING TASKS. FLIGHT EVALUATION BY THREE BOEING VERTOL PILOTS AND FOUR ARMY PILOTS (AND DEMONSTRATION FLIGHTS WITH OVER 40 AVIATORS PLUS 12-15 NONRATED PERSONNEL) HAS SHOWN THAT ADAPTABILITY IS RAPIDLY ACHIEVED TO BOTH THE CONTROLLER AND ITS CONTROL SENSITIVITY. FIGURE 30 SHOWS THIS CONTROLLER AS DESIGNED FOR THE PROTOTYPE AND INSTALLED IN THE MODEL 347 FLIGHT TEST VEHICLE.

BOEING VERTOL DOCUMENT NO. - D301-10208-2 DATED DECEMBER 1974

C. FLIGHT CONTROL SYSTEM (CONTINUED)

SWASHPLATE ACTUATOR STALL FLUTTER DAMPING - NOVEMBER 1973 - JANUARY 1974

WIND TUNNEL AND BENCH TESTS HAVE BEEN ACCOMPLISHED UTILIZING DYNAMICALLY SCALED COMPONENTS AND EXISTING SWASHPLATE HARDWARE IN AN ATTEMPT TO ACHIEVE A REDUCTION IN HLH UPPER CONTROL SYSTEM LOADS CAUSED BY ROTOR BLADE STALL FLUTTER DYNAMICS. TEST RESULTS HAVE INDICATED THAT AS MUCH AS A 50 PERCENT REDUCTION IN ACTUATOR DESIGN LOAD MAY BE ANTICIPATED. IN THIS DESIGN CONCEPT THE ACTUATOR ITSELF PROVIDES LOAD DAMPING UTILIZING CONDITIONED DIFFERENTIAL PRESSURE FEEDBACK. THE HLH PROTOTYPE ACTUATORS ARE CURRENTLY BEING DESIGNED AND FABRICATED TO PROVIDE THIS STALL FLUTTER DAMPING MODE.

BOEING VERTOL DOCUMENT NO. T301-10229-1 DATED JANUARY 1974

FLIGHT EVALUATION OF EXTERNAL LOAD STABILIZATION - AUGUST 1974

IN ATTEMPTING TO DAMP PENDULAR EXTERNAL LOAD MOTIONS, THE FLIGHT CONTROL SYSTEM MEASURES CABLE ANGLE AND POSITIONS THE AIRCRAFT IN SUCH AN ATTITUDE AS REQUIRED TO DECREASE THE LOAD MOTION IN HOVER THROUGH CRUISE MODES. AN AUTOMATIC CENTERING (AIRCRAFT OVER LOAD) FEATURE IS MECHANIZED TO PREVENT LOAD SWING INTO NEARBY OBSTRUCTIONS FOLLOWING ACQUISITION FROM CONFINED AREAS.

FIGURE 31 REFLECTS REPRESENTATIVE PRELIMINARY MODEL 347 FLIGHT TEST DATA.

BOEING VERTOL DOCUMENT NO. - D301-10208-2 DATED DECEMBER 1974

### C. FLIGHT CONTROL SYSTEM (CONTINUED)

#### PRECISION HOVER HOLD - SEPTEMBER 1974

A SELF-CONTAINED PRECISION HOVER SENSOR HAS BEEN DEMONSTRATED. THE POSITION ERROR SIGNALS PRODUCED BY THE SYSTEM ARE UTILIZED BY THE AUTOMATIC FLIGHT CONTROL SYSTEM TO PROVIDE HANDS-OFF PRECISION HOVER HOLD. TEST DATA REFLECTS THAT THE HELICOPTER CAN BE HELD TO A CIRCULAR ERROR PROBABILITY (CEP) OF 4 $\frac{1}{2}$  INCHES IN THE HORIZONTAL PLANE, WHICH IS FAR IN ADVANCE OF THE STATE-OF-THE-ART. THE PRECISION HOVER SENSOR UTILIZES A LOW POWER LASER RANGE FINDER FOR PRECISE HANDS-OFF CONTROL OF VERTICAL POSITION AND TEST DATA SHOWS THAT THIS POSITION CAN BE HELD TO 2.4 INCHES RMS. FIGURE 32 REFLECTS PRELIMINARY TEST DATA FROM THE MODEL 347 FLIGHT TEST DEMONSTRATION WHILE FIGURE 33 ILLUSTRATES THE PRECISION HOVER SENSOR INSTALLATION IN THE TEST VEHICLE.

BOEING VERTOL DOCUMENT NO. - D301-10208-2 DATED DECEMBER 1974

#### AUTOMATIC APPROACH TO HOVER - OCTOBER 1974

FEASIBILITY OF HANDS-OFF AUTOMATIC APPROACH TO HOVER HAS BEEN SUCCESSFULLY DEMONSTRATED IN FLIGHT TEST. THE AUTOMATIC FLIGHT CONTROL SYSTEM UTILIZES HEADING, LONGITUDINAL VELOCITY AND BAROMETRIC VERTICAL RATES TO CONTROL THE AIRCRAFT ON A PROGRAMED DESCENT PATH. THE SYSTEM TRANSITIONS TO RADAR ALTITUDE AND INERTIAL VELOCITY FOR AUTOMATIC AIRCRAFT FLARE AND DECELERATION TO AN INERTIAL REFERENCED HOVER. FIGURE 34 CONTAINS A REPRESENTATIVE APPROACH PROFILE FOR THIS EXERCISE.

BOEING VERTOL DOCUMENT NO. - D301-10208-2 DATED DECEMBER 1974

### C. FLIGHT CONTROL SYSTEM (CONTINUED)

#### FUTURE TECHNOLOGY GOALS - FLIGHT CONTROL SYSTEM

##### INERTIAL MEASUREMENT UNIT (IMU) EVALUATION - (NOVEMBER 1974)

DURING THIS FLIGHT EVALUATION, A STRAP-DOWN IMU WILL BE INVESTIGATED FOR USE IN ROTARY WING AIRCRAFT. THE BASIC DIFFERENCE IN THIS TYPE OF UNIT AND THE IMU USED IN THE ATC AFCS IS THAT THE STRAP-DOWN UNIT CONTAINS NO GIMBALS. THE GIMBAL FUNCTION IS REPLACED BY A COMPUTER WHICH KEEPS TRACK OF THE RELATIVE IMU MOTION. SUCCESSFUL EVALUATION OF THIS SYSTEM COULD RESULT IN BOTH REDUCED COST AND TECHNICAL COMPLEXITY NOW ASSOCIATED WITH THE GIMBALED IMU. BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

##### COMPLETELY INTEGRATED FLY-BY-WIRE SYSTEM - MARCH-OCTOBER 1976

THE HLH PROTOTYPE WILL BE THE FIRST HELICOPTER FOR WHICH THE INITIAL DESIGN UTILIZES A FLY-BY-WIRE FLIGHT CONTROL SYSTEM. WHEREAS THE ATC FLY-BY-WIRE DEMONSTRATION CONFIRMED THE BASIC PRINCIPLES, THE PROTOTYPE WILL PROVE THE VALIDITY OF A COMPLETE DESIGN. THE PROTOTYPE HLH WILL ALSO USE NEW COCKPIT CONTROLS WHICH ARE COMPATIBLE WITH THE SURVIVABILITY AND FLIGHT SAFETY RELIABILITY OF THE MULTI-CHANNEL FLY-BY-WIRE SYSTEM. REDUNDANT ELECTRICAL/HYDRAULIC POWER WILL BE PROVIDED, CONFIGURED TO SUPPORT THE TWO FAIL-OPERATE REDUNDANCY LEVEL WHILE THE SWASHPLATE WILL BE CONTROLLED BY MULTI-REDUNDANT ELECTROHYDRAULIC CONTROL STAGES INTEGRATED WITH NECESSARY POWER ACTUATORS. FIGURE 35 CONTAINS A FUNCTIONAL DESCRIPTION OF THE FLY-BY-WIRE CONFIGURATION DEPICTING THE MULTIPLICITY OF INTERFACING REDUNDANT SYSTEMS. BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

C. FLIGHT CONTROL SYSTEM (CONTINUED)

FLIGHT DEMONSTRATION OF INTEGRATED SWASHPLATE SERVO-ACTUATORS - MARCH-OCTOBER 1976

A FLY-BY-WIRE ACTUATOR, WHICH INTEGRATES A DUAL POWER OUTPUT STAGE WITH A TRIPLEX CONTROL STAGE WILL BE DEMONSTRATED. THE TECHNOLOGY OF THIS DESIGN PROVIDES OPTIMIZATION OF REDUNDANT ELECTROHYDRAULIC CONTROL INTERFACE WITH REDUNDANT FLY-BY-WIRE ELECTRONICS. THE ATC FEASIBILITY DEMONSTRATION PROGRAM USED A DRIVER ACTUATOR WHICH CONTROLLED THE EXISTING SWASHPLATE POWER ACTUATORS ON THE MODEL 347 HELICOPTER. THE INTEGRATED ACTUATOR CONCEPT IS COMPATIBLE WITH DUAL AND TRIPLE REDUNDANCY AND THE POWER OUTPUT STAGE CAN BE SIZED TO ANY LOAD REQUIREMENT WITHOUT AFFECTING THE INTEGRITY OF THE CONTROL STAGE. THIS TECHNOLOGY IS READILY TRANSFERABLE TO OTHER FLY-BY-WIRE SYSTEMS. IN ADDITION, PRESSURE TRANSDUCERS AND SERVO-ELECTRONICS TO MODIFY ACTUATOR STIFFNESS HAVE BEEN INCORPORATED TO PROVIDE DAMPING OF BLADE STALL FLUTTER MODES. THIS INNOVATIVE CONCEPT WILL BE EVALUATED ON THE PROTOTYPE HLH. BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

DEMONSTRATE IMPROVED HOVER CONTROLLABILITY AND COMPLETE CARGO OPERATIONS -  
MARCH - OCTOBER 1976

THE HLH WILL BE THE FIRST HELICOPTER TO DEMONSTRATE THE EFFICIENCY OF EXTERNAL LOAD OPERATIONS UTILIZING IMPROVED AIRCRAFT CONTROLLABILITY IN CONJUNCTION WITH AN OPERABLE CARGO HOIST AND DUAL SUSPENSION SYSTEM. A SENSITIVE LOAD CONTROLLING CREWMAN'S CONTROLLER AND INERTIALLY REFERENCED HOVER HOLD WERE DEMONSTRATED IN THE MODEL 347 FLIGHT TESTING. THE HLH ADVANCED CARGO SYSTEM WAS BENCH TESTED ON A TOWER. THE HLH PROTOTYPE, UTILIZING THESE ATC SYSTEMS, WILL DEMONSTRATE A TOTALLY INTEGRATED CARGO OPERATION. BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

C. FLIGHT CONTROL SYSTEM (CONTINUED)

DEMONSTRATE ADVANCED STABILITY AND CONTROL FOR A LARGE TRANSPORT HELICOPTER -  
MARCH-OCTOBER 1976

UNDER THE ATC PROGRAM, THE FEASIBILITY OF ADVANCED CONTROL LAWS WAS ESTABLISHED. THESE CONTROL CONCEPTS WILL BE MATCHED TO THE DYNAMIC CHARACTERISTICS OF THE HLH PROTOTYPE. THUS, THE PROTOTYPE WILL BE THE FIRST HELICOPTER TO UTILIZE THE DIGITAL AUTOMATIC FLIGHT CONTROL SYSTEM WHICH IS NOW INSTALLED IN AN EXPERIMENTAL CONFIGURATION.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

# FIRST ROTARY WING FLY BY WIRE DEMONSTRATION

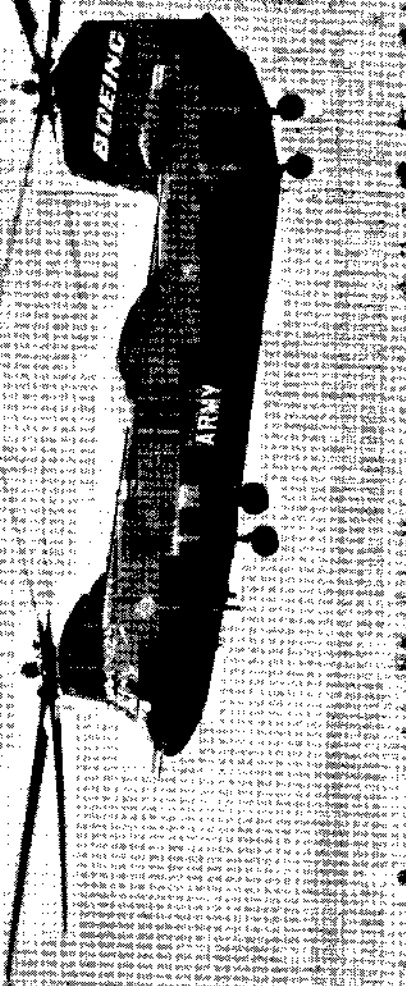


FIGURE 21

# FLIGHT RESEARCH VEHICLE SYSTEM

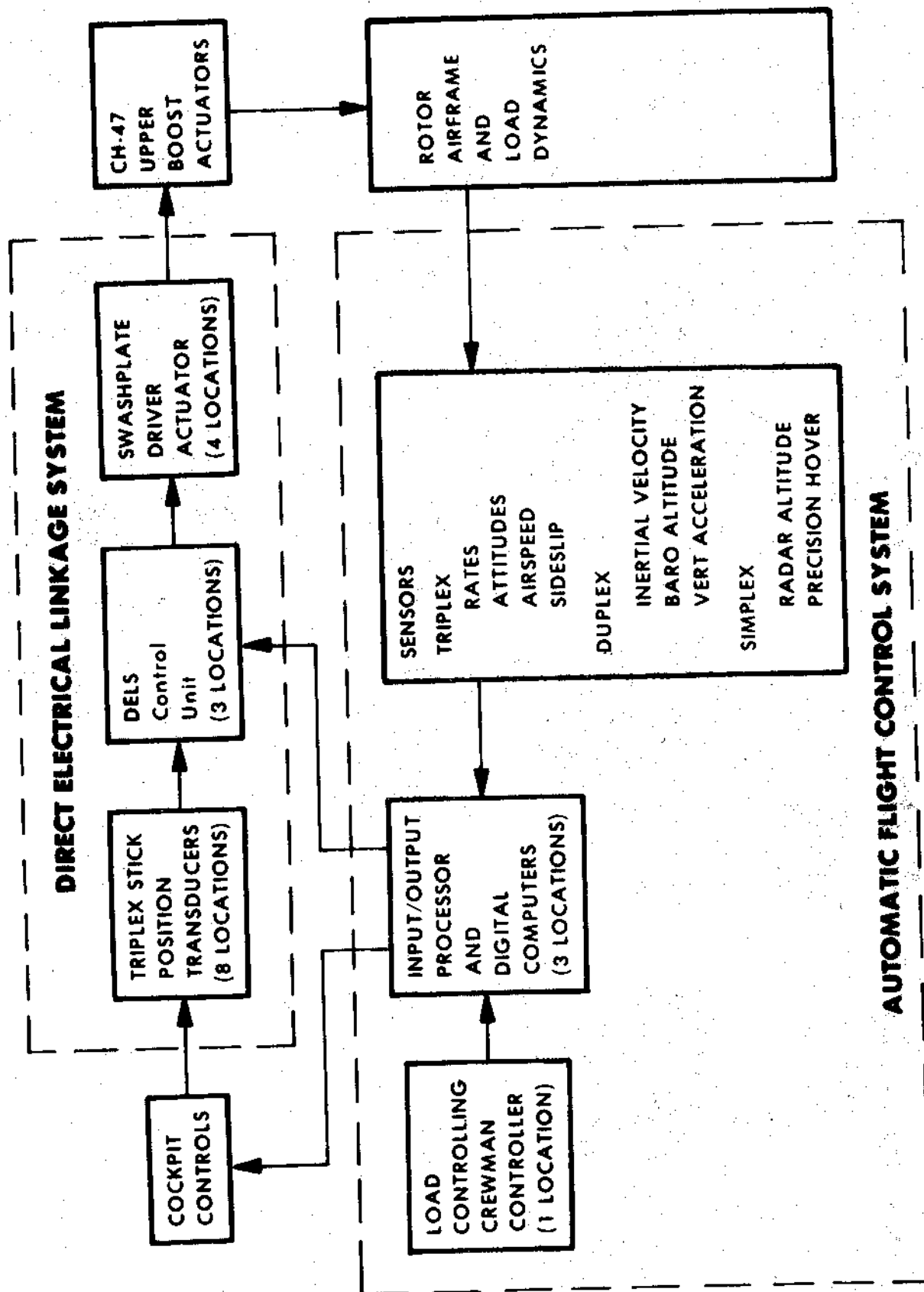


FIGURE 22

# FLY-BY-WIRE COMPONENTS OF HLH FLIGHT DEMONSTRATION

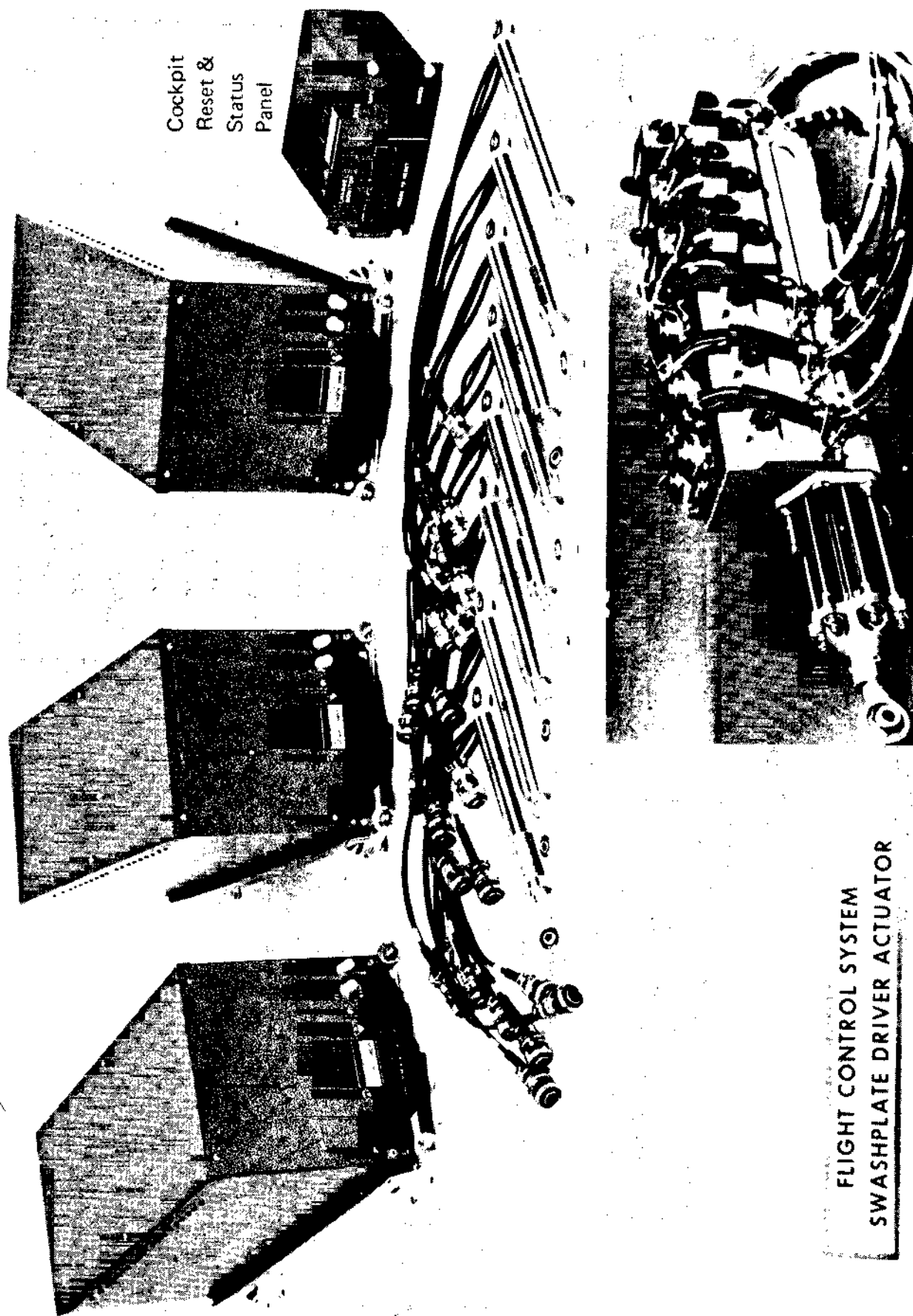
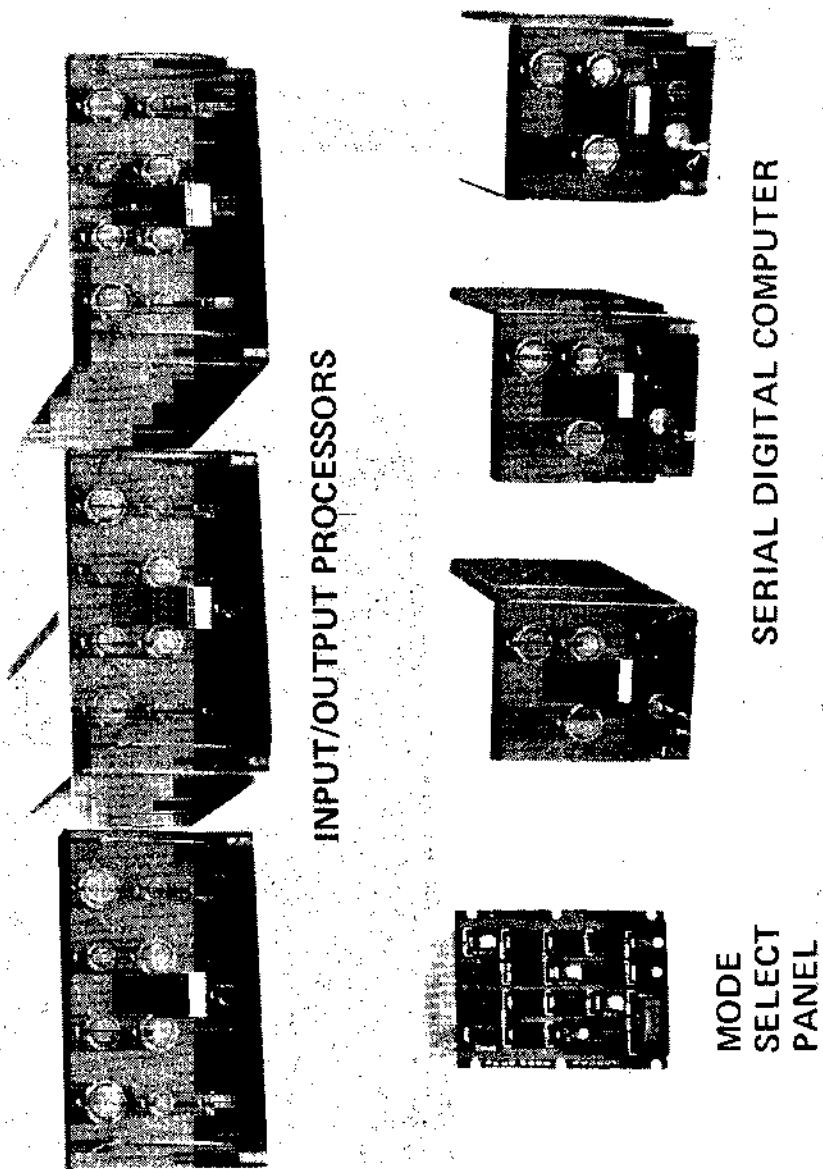


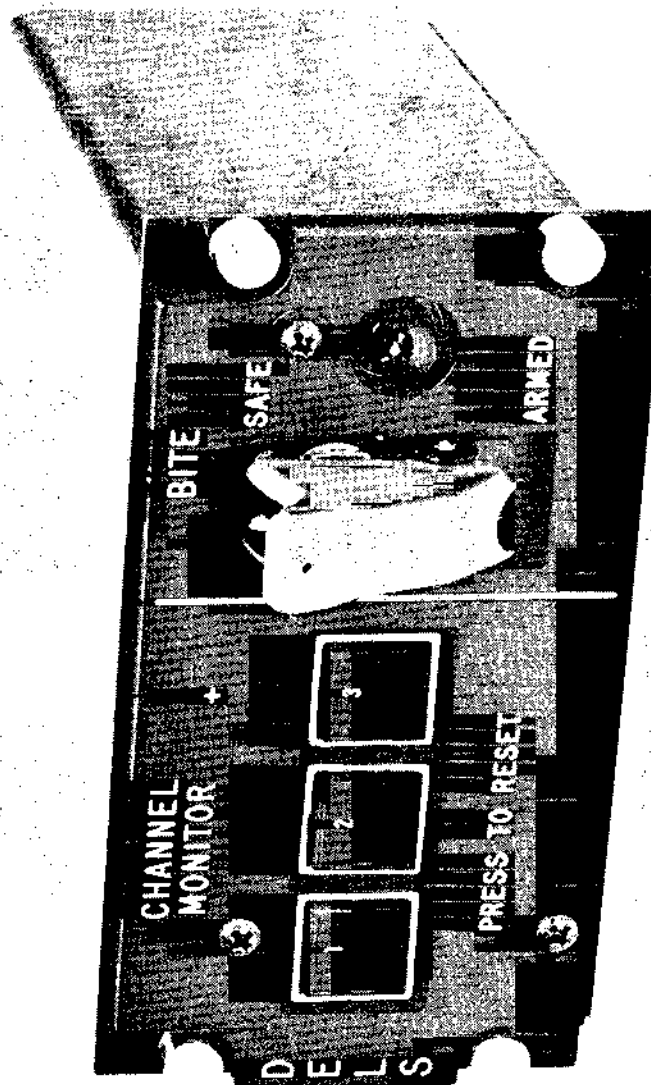
FIGURE 23

# **FLIGHT RESEARCH VEHICLE AUTOMATIC FLIGHT CONTROL SYSTEM COMPONENTS**



**FIGURE 24**

**PILOT STATUS PANEL**



**FIGURE 25**

# FAILURE STATUS PANEL

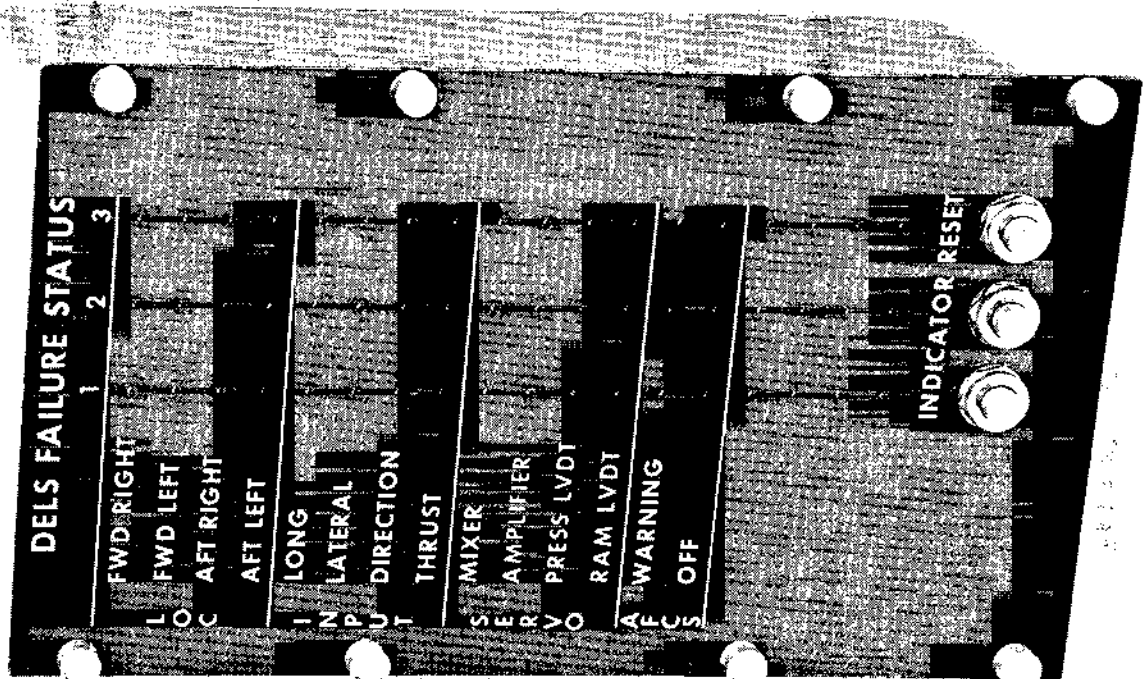


FIGURE 26

# BITE PANEL

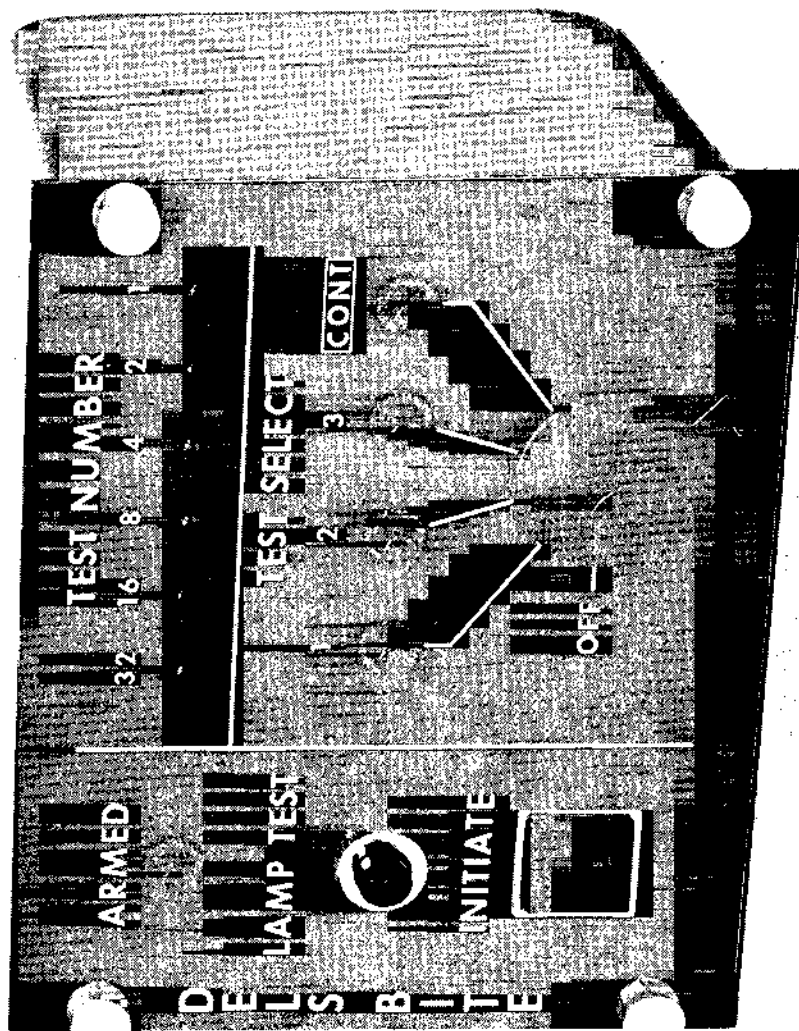


FIGURE 27

## HLH AFCS HANDLING QUALITIES

Axis	Stability		Maneuverability	
	Hover & Low Speed	Forward Flight **	Hover & Low Speed	Forward Flight **
Longitudinal*	Ground Speed Hold	Airspeed Hold	Ground Speed Demand	Airspeed Demand
Lateral*	Ground Speed Hold	Bank Angle Hold (Any Bank Angle)	Ground Speed Demand	Bank Angle For Bank Angles $< \pm 10^\circ$ Roll Rate For Angles $> \pm 10^\circ$ Automatic Turn Coordination
Vertical	Velocity Damping	Velocity Damping	Altitude Rate	Altitude Rate
Directional*	Heading Hold	Heading Hold	Heading Rate	Sideslip
* Vernier Control (Beep) Provided      ** Greater Than 45 kt				

**FIGURE 28**

# HLH AUTOMATIC FLIGHT CONTROL SYSTEM MODES

UNAugmented  
AIRCRAFT — VFR

BASIC MODE  
ENGAGE  
4 AXIS SCAS

PENDULAR  
MODE  
DAMPING

ALTITUDE  
HOLD

AUTOMATIC  
APPROACH  
TO HOVER

REFERENCE  
BAROMETRIC

HOVER HOLD  
AIRCRAFT POSITION HOLD  
ICC CONTROL  
LOAD STABILIZATION

FIGURE 29

# LOAD CONTROLLING CREW STATION FOUR AXIS CONTROLLER

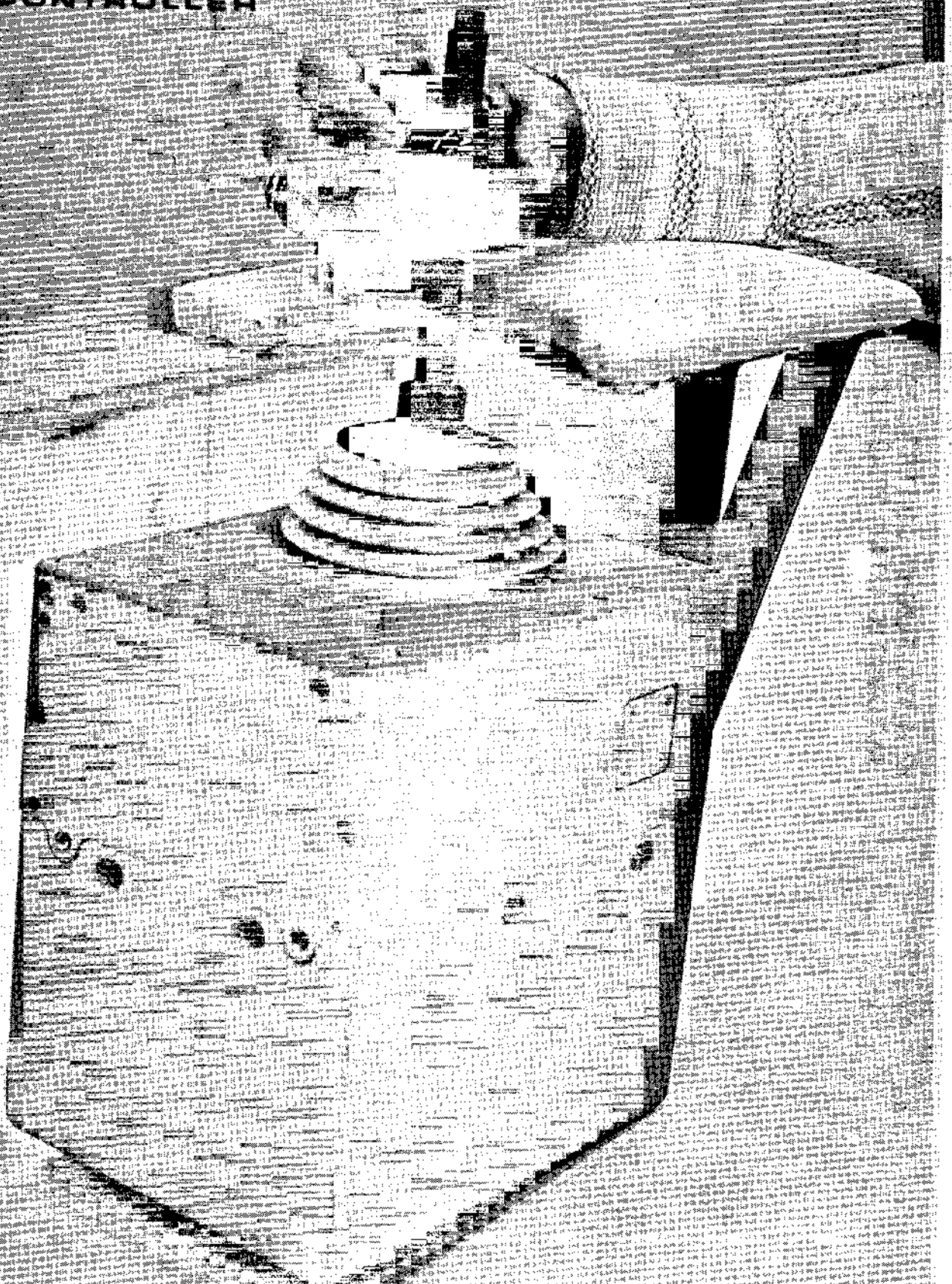


FIGURE 30

# HLH ATC FLIGHT CONTROL SYSTEM AUTOMATIC LOAD STABILIZATION

10 FT. INVERTED VEE CABLES

HOVER HOLD ON

LSS ON

LSS OFF

EXCITATION  
STOPPED

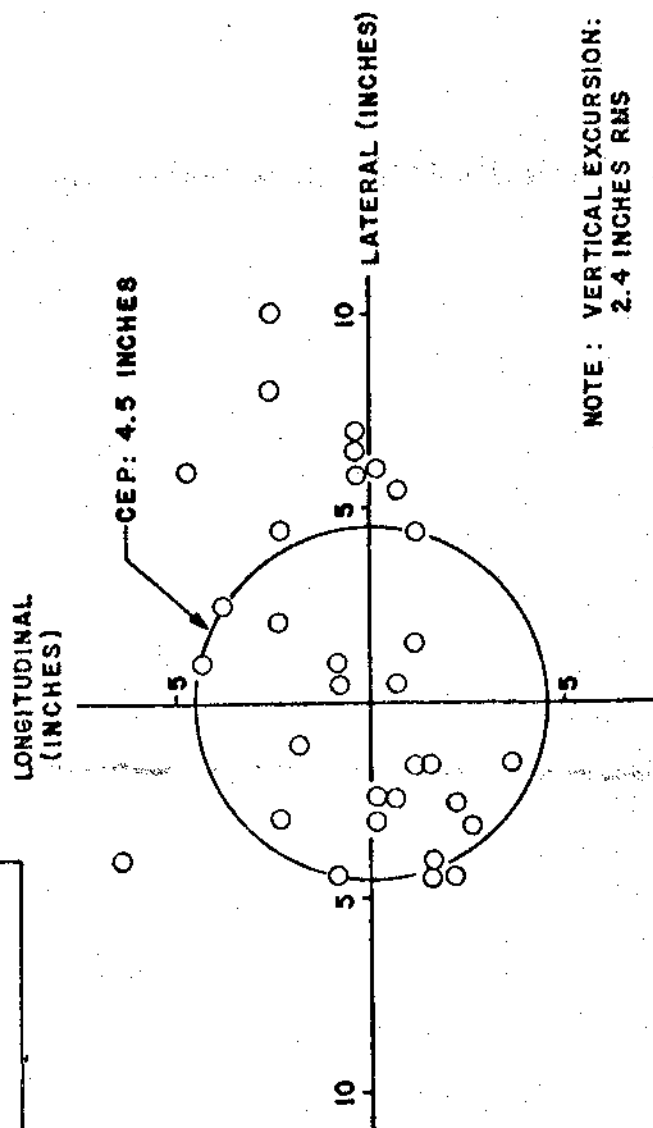
30  
20  
10  
0  
10  
20  
30  
AFT  
FWD  
FORWARD  
HOOK  
LONG.  
POSITION  
(DEGREES)

20  
15  
10  
5  
0  
TIME (SECONDS)

FIGURE 31

# HLH ATC PRECISION HOVER

DATA: 2 MINUTES HANDS OFF HOVER  
EQUIPMENT: PRECISION HOVER SENSOR  
IN 347 HELICOPTER  
INSTRUMENTATION: GROUND BASED  
70MM CAMERA  
CONDITIONS: ALTITUDE: 40 FEET  
WIND: 10 KNOTS



NOTE: VERTICAL EXCURSION:  
2.4 INCHES RMS

FIGURE 32

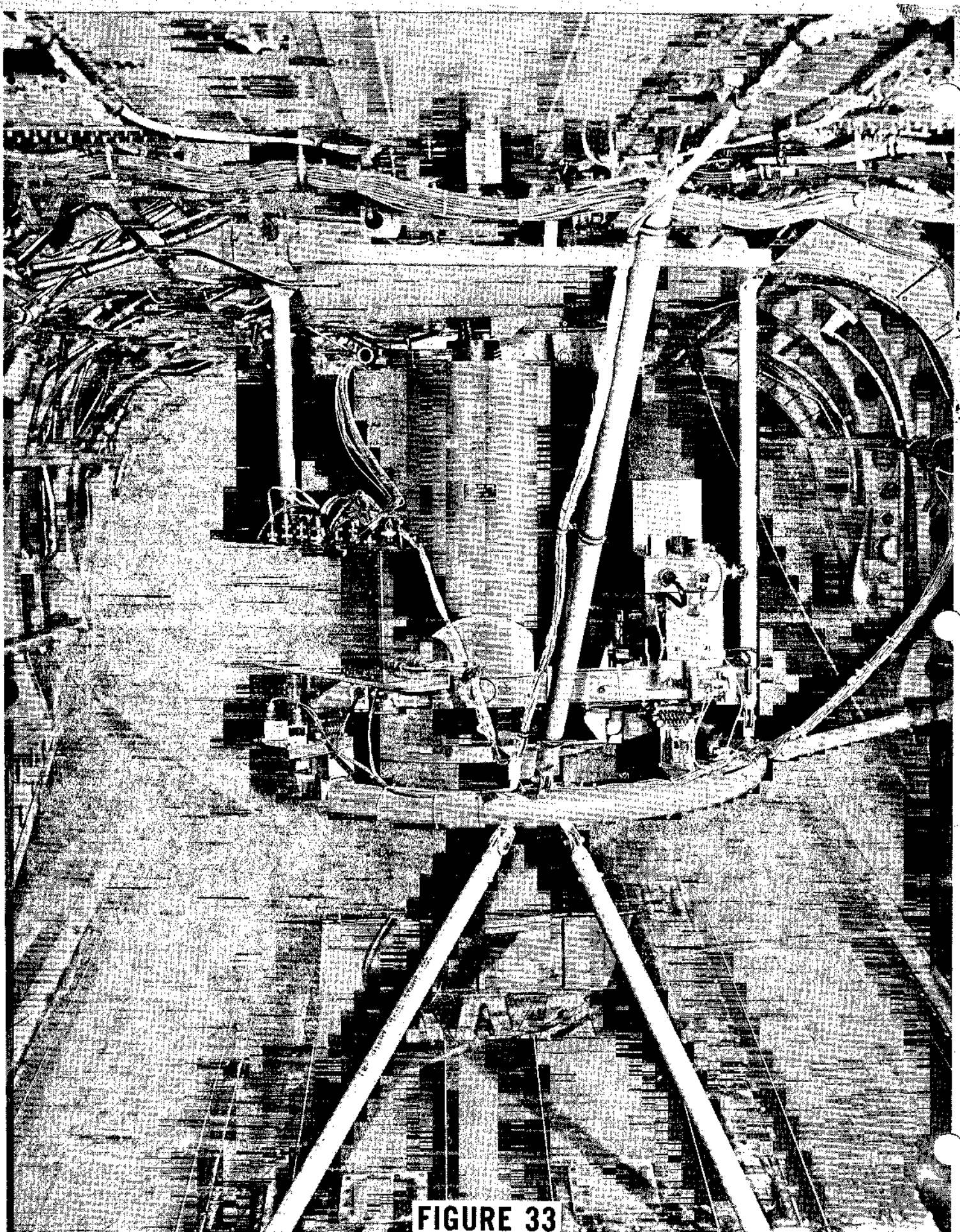
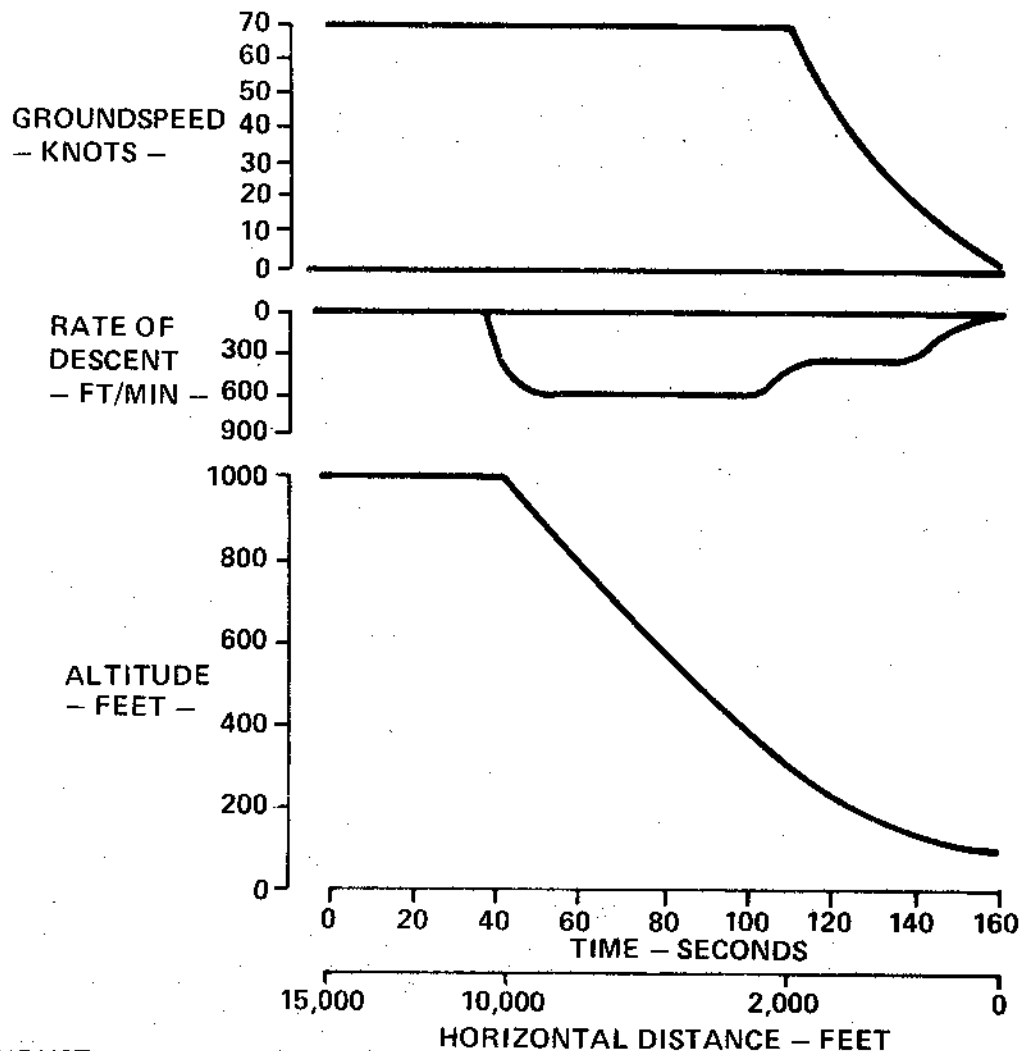


FIGURE 33

# AUTOMATIC APPROACH TO HOVER

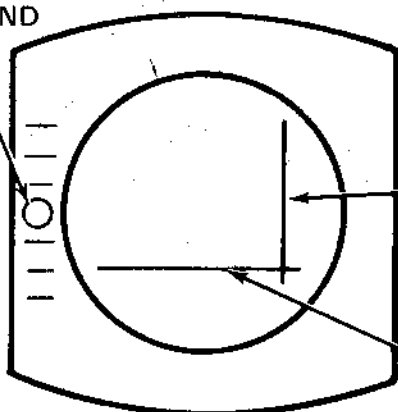
OBJECTIVE: DEVELOP COMPUTATION REQUIREMENTS  
FOR APPROACH FROM CRUISE TO HOVER

## APPROACH PROFILE



THRUST  
COMMAND

DISPLAY



## PILOT INTERFACING

AUTOMATIC - PILOT MONITORS  
DISPLAY

SEMI AUTOMATIC - PILOT FOLLOWS  
DISPLAY COMMANDS

**FIGURE 34**

## 4 AXIS DUALIZED



#### D. CARGO HANDLING SYSTEM

## D. CARGO HANDLING SYSTEM

### PAST TECHNOLOGY ACCOMPLISHMENTS

#### TANDEM SUSPENSION - MARCH 1973

THE HLH CONFIGURATION EMPLOYS A TANDEM SUSPENSION SYSTEM (FIG. 36). EACH OF THE SYSTEMS' HOISTS CAN BE OPERATED INDIVIDUALLY OR SYNCHRONOUSLY. THE INDIVIDUALLY ADJUSTABLE FEATURE ALLOWS AN EXTERNAL LOAD TO BE IN-FLIGHT REPOSITIONED TO REDUCE DRAG AND INCREASE STABILITY. THE CAPABILITY FOR PERFORMANCE OPTIMIZATION DURING HOVER AND FORWARD FLIGHT IS NEW TO CRANE CONFIGURED HELICOPTERS. THE HLH IS THE ONLY AIRCRAFT ORIGINALLY DESIGNED TO USE A DUAL SUSPENSION SYSTEM. IN ADDITION, THE DUAL HOOK CONFIGURATION CAN BE CONFIGURED TO A SINGLE-POINT HOOK SYSTEM, IF REQUIRED, IN LESS THAN 15 MINUTES.

BOEING VERTOL DOCUMENT NOS. - BOEING VERTOL MEMO 8-7442-1-573 DATED SEPTEMBER 1973

AND D301-10193-1 DATED JANUARY 1973

#### PAIRED CABLE TENSION MEMBERS - MARCH 1973

EACH TENSION MEMBER CONSISTS OF A PAIRED CABLE ARRANGEMENT. THE CABLES ARE OF LEFT-HAND AND RIGHT-HAND CONSTRUCTION TERMINATING AT AN EQUALIZING BAR AT THE COUPLING ATTACHMENT. THIS TORQUE-BALANCED SYSTEM, TOGETHER WITH THE ADVANCED CABLE DESIGN, RESULTS IN A SMALL DIAMETER (.72 INCH) LIGHTWEIGHT TENSION MEMBER. THE SMALL DIAMETER AND INCREASED FLEXIBILITY OF EACH CABLE RESULTS IN REDUCED DIAMETER CABLE DRUMS, A SMALLER ENVELOPE AND LOWER WEIGHT. THE PAIRED CABLES PROVIDE REDUNDANCY AS EACH CABLE IS CAPABLE OF CARRYING THE DESIGN LOAD (22.5 TONS) AT A REDUCED INERTIA FACTOR OF 2G'S. THE 36 X 7 CONSTRUCTION GEOMETRY (FIG. 37) PROVIDES THE DIAMETER REDUCTION REQUIRED TO ACHIEVE THE

#### D. CARGO HANDLING SYSTEM (CONTINUED)

ABOVE BENEFITS. THIS GEOMETRY FURTHER PROVIDES FOR INCREASED CABLE FLEXIBILITY AND FLEXIBILITY IS A KEY TO INCREASED CABLE LIFE. CABLE TECHNOLOGY EXPLORATIONS IN THE DEVELOPMENT OF THE HLH TENSION MEMBER HAS PRODUCED LONG LIFE, HIGH STRENGTH CABLES SUBSTANTIALLY BETTER THAN EXISTING COMMERCIALY AVAILABLE HARDWARE.

BOEING VERTOL DOCUMENT NOS. D301-10178-2 DATED NOVEMBER 1973 AND

D301-10193-1 DATED JANUARY 1973

#### DUAL DRUM HOIST SYSTEM - MARCH 1973

THE DUAL DRUM HOIST HAS DRUMS THAT TRAVERSE Laterally AS CABLE IS DEPLOYED, THUS ENSURING THE CABLE LEAVES THE AIRCRAFT AT A CONSTANT LOCATION, ELIMINATING LATERAL CG CHANGES AS A LOAD IS HOISTED. THE DUAL DRUM WINCH (FIG. 38) PROVIDES REDUNDANCY IN THAT ONE HALF OF THE WINCH WILL FUNCTION AND RETAIN THE LOAD IN THE EVENT OF FAILURE IN THE OPPOSITE HALF. THE DUAL DRUM CONCEPT COMBINED WITH THE BENEFITS DERIVED FROM THE PAIRED CABLE TENSION MEMBERS' DEVELOPMENT HAS RESULTED IN AN AIRBORNE SYSTEM HAVING A NEAR 50 PERCENT WEIGHT REDUCTION FOR AN EQUIVALENT LOAD CAPACITY OF EXISTING SYSTEMS. THE HLH HOIST SYSTEM HAS DEMONSTRATED THE CAPACITY TO HANDLE ITS DESIGN LIMIT LOAD OF 70 TONS.

BOEING VERTOL DOCUMENT NO. D301-10212-2 DATED JULY 1974

#### PNEUMATIC HOIST DRIVE - MARCH 1973

THE HOIST IS POWERED BY AN AIR TURBINE MOTOR, THE AIR BEING SUPPLIED FROM ENGINE BLEED OR FROM A PNEUMATIC POWER GENERATOR (FIG. 39). THE AIR IS AT A RELATIVELY LOW PRESSURE, PROVIDING A SAFE POWER TRANSFER SYSTEM TOLERANT TO MINOR DAMAGE. THE USE OF PNEUMATIC POWER ELIMINATES THE FIRE HAZARD THAT WOULD RESULT FROM HYDRAULIC SYSTEM LEAKAGE. DYNAMIC BRAKING OF A LOAD BEING LOWERED

#### D. CARGO HANDLING SYSTEM (CONTINUED)

PERMITS PRECISE CONTROL AT ALL TIMES. THE AIR TURBINE MOTOR DRIVES THROUGH A BRAKE ASSEMBLY THAT IS RELEASED ONLY WHEN THE AVAILABLE TORQUE MATCHES THE LOAD, ENSURING A FAIL-SAFE SYSTEM. DYNAMIC BRAKING ELIMINATES THE MAJOR PROBLEM ASSOCIATED WITH MECHANICAL BRAKES, HIGH HEAT ENERGY DISSIPATION, THUS ENABLING CONSTRUCTION OF A MUCH SIMPLIFIED, MORE RELIABLE SYSTEM.

BOEING VERTOL DOCUMENT NOS. D301-10180-2 DATED NOVEMBER 1974 AND

D301-10193-1 DATED JANUARY 1973

#### CARGO COUPLING - MARCH 1973

THE CARGO COUPLING (FIG. 40) INCORPORATES A FULL 360° SWIVEL CAPABILITY WITHOUT REQUIRING SLIP RINGS TO TRANSFER ELECTRIC SIGNALS. THE ELIMINATION OF SLIP RINGS FROM THE COUPLING DESIGN AND AT THE AIRFRAME MOUNTED CONDUCTOR REEL (FIG 41) MECHANISM RESULTS IN A SIGNIFICANT IMPROVEMENT IN THE SYSTEM'S RELIABILITY. THE COUPLING INCORPORATES A LOAD LOCK-OUT FEATURE THAT PREVENTS INADVERTENT LOAD RELEASE AT ANY TIME, RESULTING IN IMPROVED SYSTEM SAFETY.

BOEING VERTOL DOCUMENT NOS. D301-10184-2 DATED JANUARY 1974 AND

D301-10193-1 DATED JANUARY 1973

#### CARGO HANDLING SYSTEM INTEGRATED TEST RIG - OCTOBER 1973 - APRIL 1974

THE ENTIRE CARGO HANDLING SYSTEM (CHS) WAS INSTALLED IN A TEST TOWER KNOWN AS THE INTEGRATED TEST RIG (FIG. 42). THIS WAS THE FIRST INTEGRATION OF ALL THE ADVANCED TECHNOLOGY COMPONENTS AS AN OPERABLE SYSTEM. THE SYSTEM WAS SUCCESSFULLY DEMONSTRATED IN BOTH THE DUAL- AND SINGLE-POINT MODES FOR A TOTAL OF MORE THAN 1800 CYCLES OF OPERATION (ONE CYCLE CONSISTS OF: DEPLOY CABLE UNLOADED, HOIST 29-TON LOAD, LOWER AND RELEASE 29-TON LOAD, AND HOIST UNLOADED). IN ADDITION, THIS RIG WAS UTILIZED TO DEMONSTRATE A STATIC CAPABILITY IN EXCESS OF 70 TONS, THE CHS DESIGN LIMIT LOAD.

BOEING VERTOL DOCUMENT NO. D301-10100-12 DATED 12 JULY 1974

D. CARGO HANDLING SYSTEM (CONTINUED)

ELECTROSTATIC DISCHARGE SYSTEM - NOVEMBER 1973

UNDER THE ADVANCED TECHNOLOGY COMPONENT PROGRAM, BOEING VERTOL TOGETHER WITH STANFORD RESEARCH INSTITUTE UNDERTOOK A STUDY OF THE POTENTIAL EQUALIZATION BETWEEN A HOVERING HELICOPTER AND THE GROUND DURING EXTERNAL CARGO HANDLING OPERATIONS. THE EFFECTS OF LARGE ELECTROSTATIC DISCHARGES ENCOUNTERED COULD LEAD TO SERIOUS INJURY TO GROUND PERSONNEL WHO TOUCH THE HOOK OF A HOVERING HELICOPTER. ACTIVE DISCHARGE SYSTEMS WERE INVESTIGATED BUT DATA INDICATED IT WAS NOT VIABLE DUE TO ERRORS IN SENSING UNDER CONDITIONS OF HIGH TRIBOELECTRIC CHARGING SUCH AS HOVERING IN DUST. THE ONLY VIABLE METHOD OF DISCHARGING A HELICOPTER UNDER ALL CONDITIONS WAS BY A RESISTIVE GROUNDING LINE (FIG. 43) HANGING BELOW THE HLH CARGO COUPLING.

BOEING VERTOL DOCUMENT NO. - T301-10194-1 AND -2 DATED APRIL 1974

D. CARGO HANDLING SYSTEM (CONTINUED)

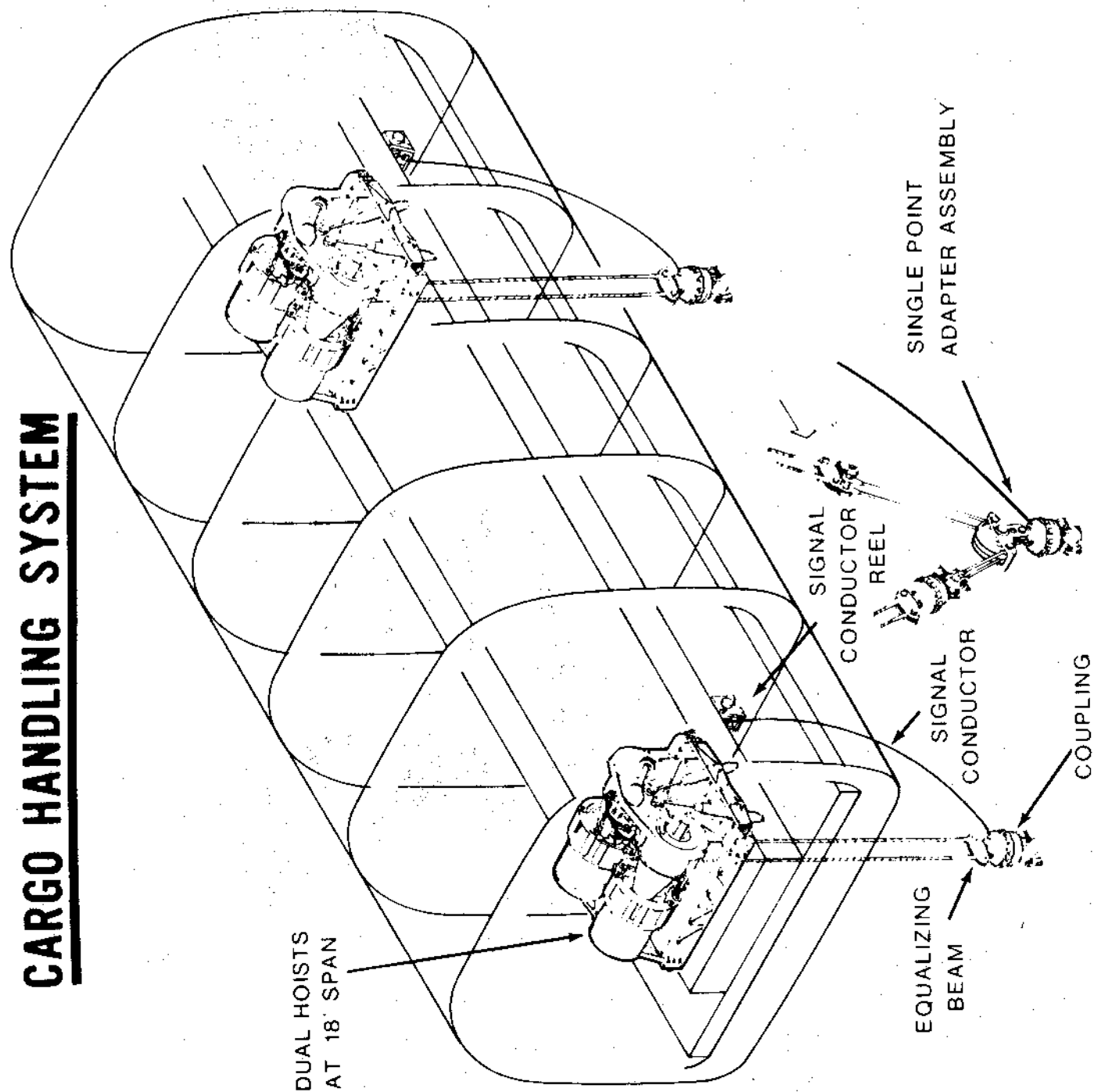
FUTURE TECHNOLOGY GOALS

CARGO HANDLING SYSTEM INTEGRATED TEST - MARCH-SEPTEMBER 1976

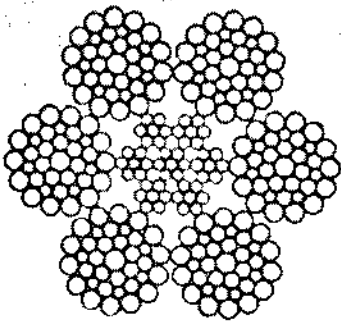
THE ENTIRE CARGO HANDLING SYSTEM WILL BE INSTALLED AND INTEGRATED INTO THE PROTOTYPE HLH FOR FLIGHT TEST. THIS WILL DEMONSTRATE SYSTEM COMPATIBILITY WITH THE ADVANCED AIRFRAME AND THE BENEFITS OF A DUAL MODE, IN-FLIGHT OPERABLE SYSTEM OF A TYPE WHICH HAS NEVER FLOWN BEFORE.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

# CARGO HANDLING SYSTEM



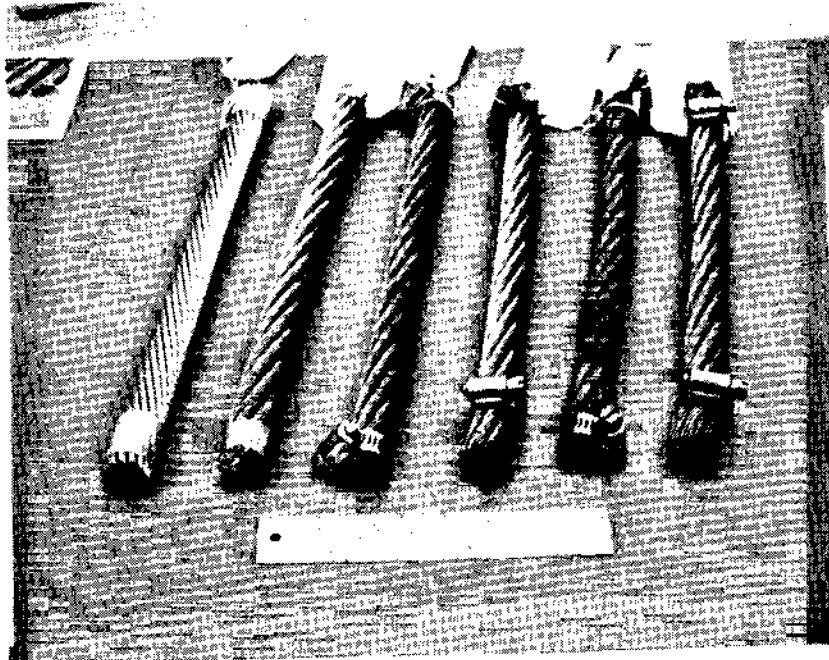
**FIGURE 36**



6 x 36 Warrington-Seale,  
IWRC Construction.



36 x 7 Lang Lay



.78 INCH DESIGN SUPPORT TEST CABLES (LEFT TO RIGHT):

ELECT. GALV. 36 X 7 LANG LAY  
 ELECT. GALV. 6 X 36 LANG LAY  
 BRIGHT CARBON STEEL 6 X 36 LANG LAY  
 17-7 PH 6 X 36 LANG LAY,  
 BRIGHT CARBON STEEL 6 X 36 REGULAR LAY  
 18-2 Mn 6 X 36 LANG LAY

FIGURE 37

HOIST WINCH

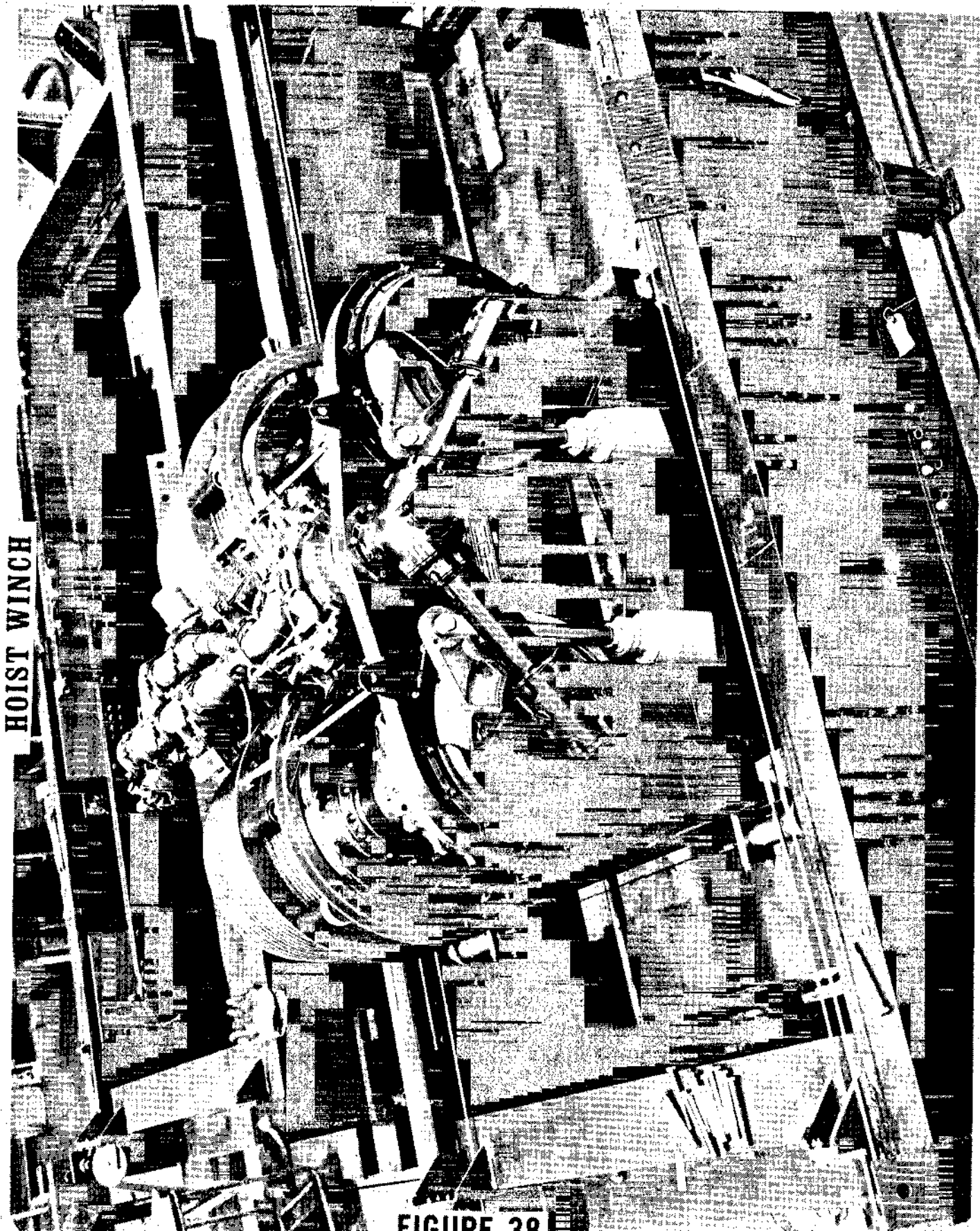
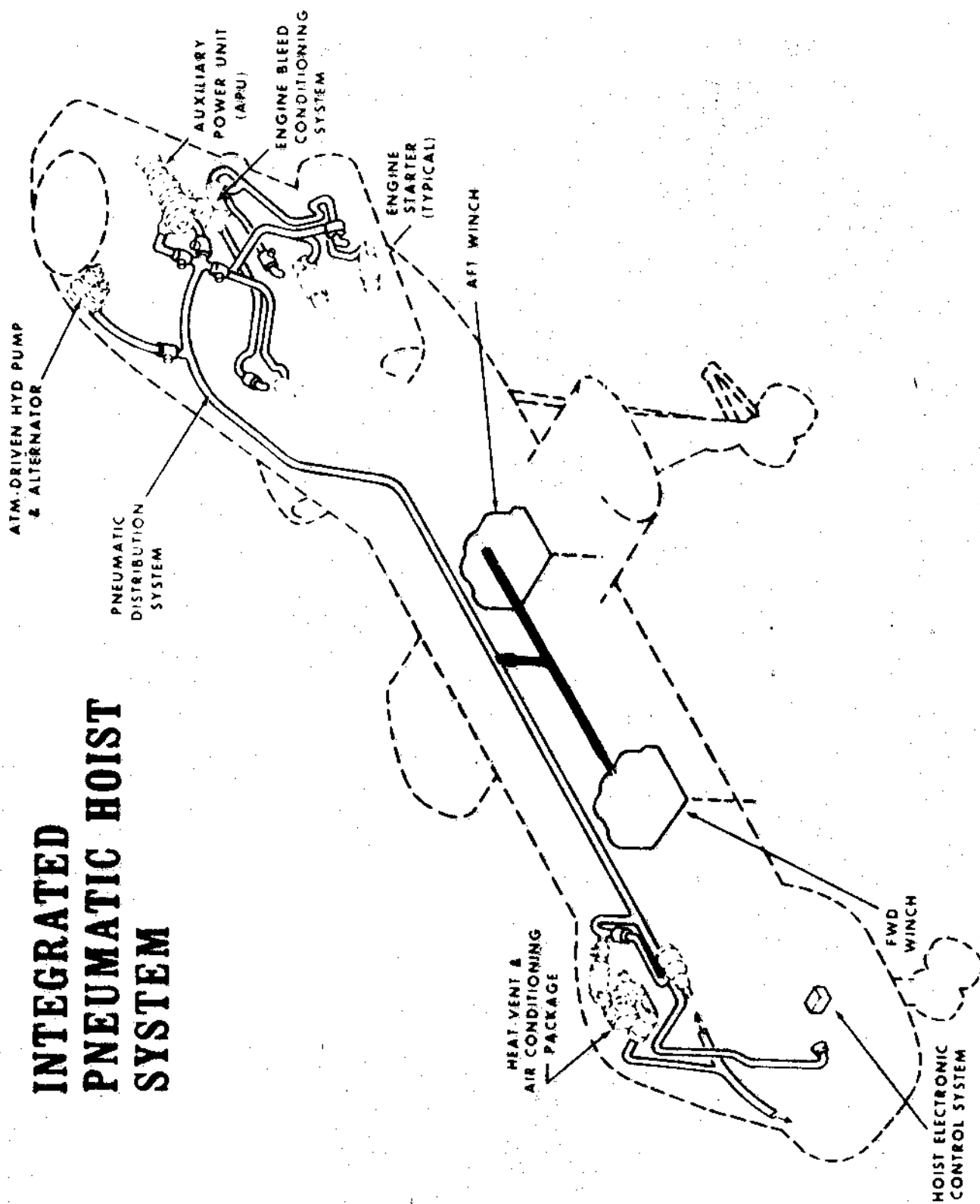


FIGURE 38

# **INTEGRATED PNEUMATIC HOIST SYSTEM**



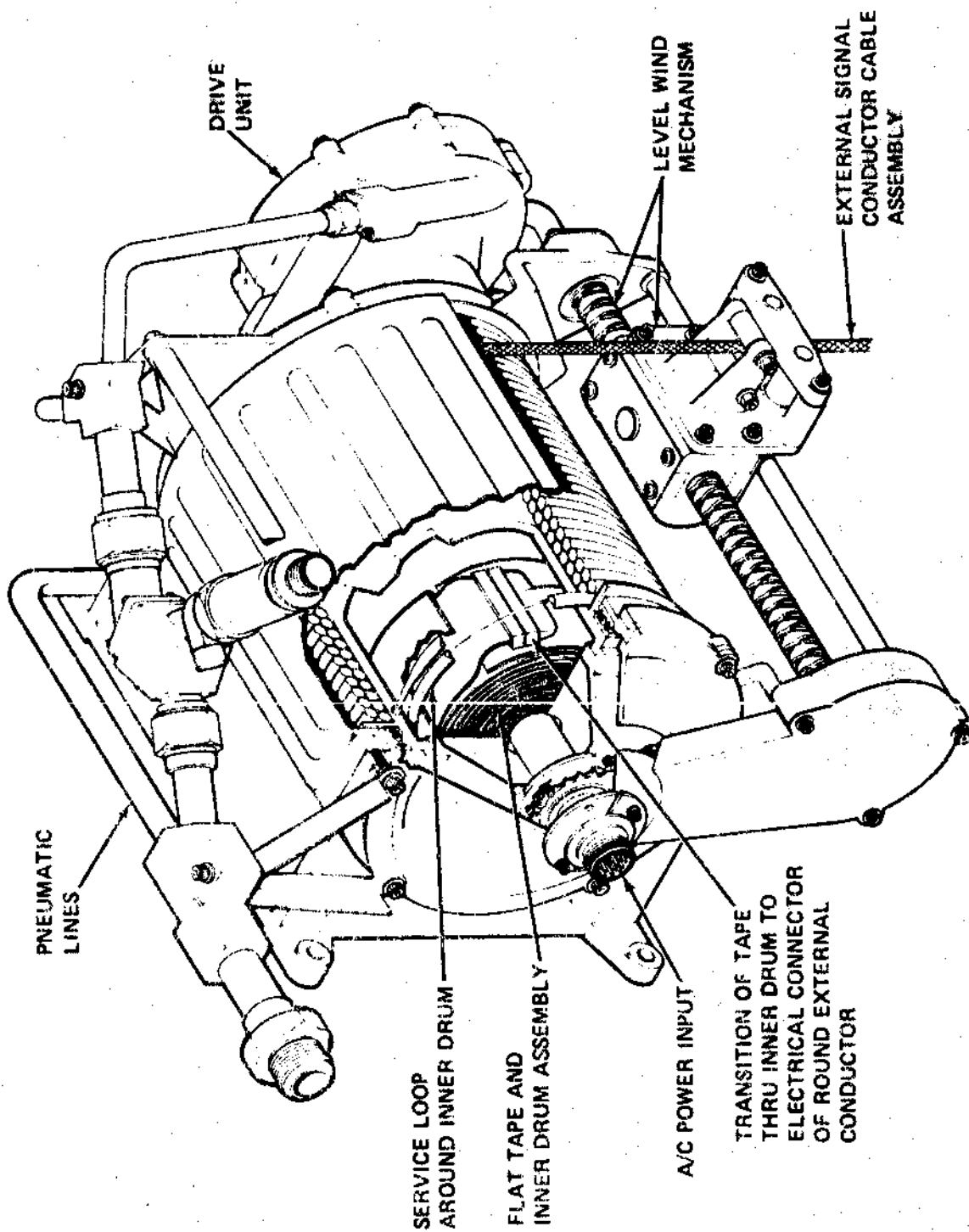
**FIGURE 39**

# CARGO HOOK SINGLE POINT ADAPTER

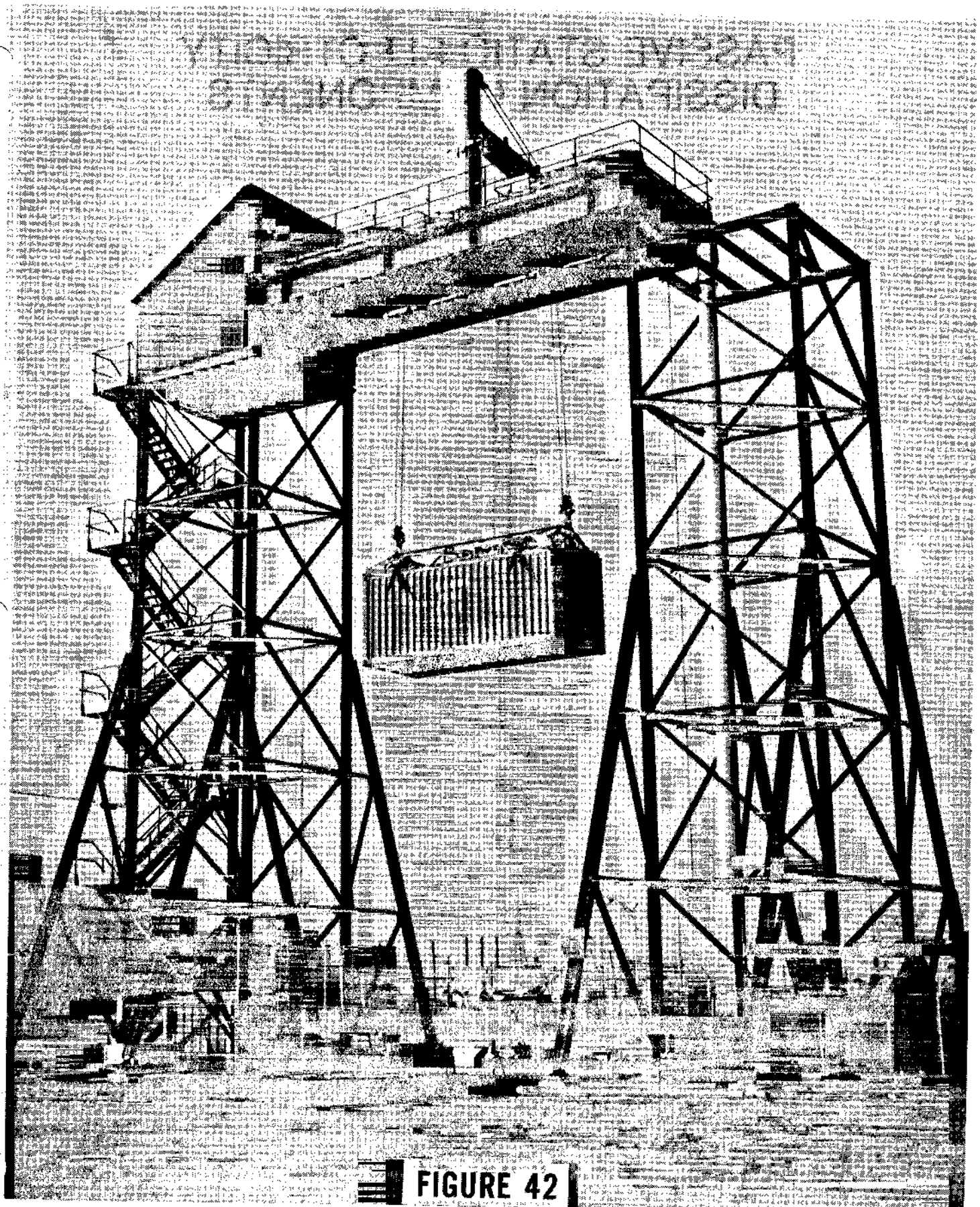
SINGLE POINT  
ADAPTER

COUPLING

FIGURE 40

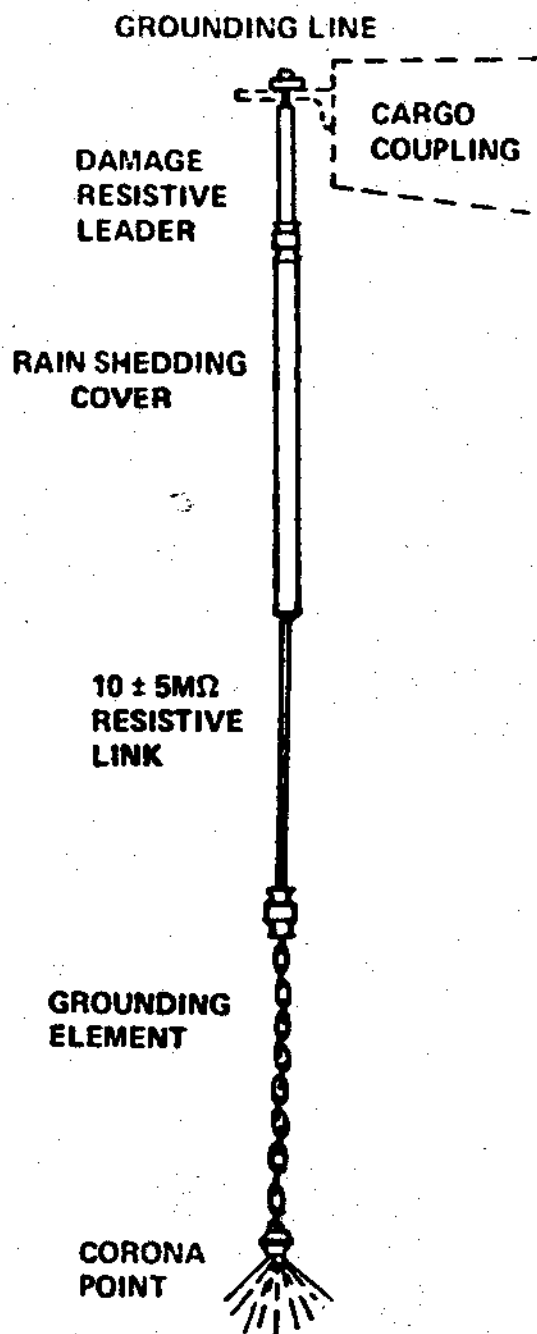


**FIGURE 41**



**FIGURE 42**

# PASSIVE STATIC ELECTRICITY DISSIPATION COMPONENTS



**FIGURE 43**

E. XT701-AD-700 ENGINE

## E. XT701-AD-700 ENGINE

### PAST TECHNOLOGY ACCOMPLISHMENTS - XT701-AD-700 ENGINE

#### INCREASED SHAFT HORSEPOWER TO WEIGHT RATIOS - FEBRUARY 1974

IN FEBRUARY 1974, THE XT701 ENGINE DEMONSTRATED THE CAPABILITY TO PRODUCE ITS DESIGN OUTPUT POWER OF 8079 SHP. FURTHER, THE CURRENT ENGINE HAS BEEN BUILT AT 32 POUNDS UNDER THE SPECIFICATION WEIGHT OF 1179 POUNDS. THE RATIO OF RATED OUTPUT POWER TO SPECIFICATION WEIGHT IS 6.8 HORSEPOWER/POUND, AS SHOWN IN FIGURE 44, WHICH IS SIGNIFICANTLY BETTER THAN ENGINES INSTALLED IN TODAY'S CARGO HELICOPTERS.

ALLISON DESIGN REPORT NO. 8166 DATED APRIL 1974

#### FLY-BY-WIRE FUEL CONTROL - FEBRUARY 1974

ENGINE FUEL CONTROLS ON CURRENT ARMY HELICOPTERS HAVE MECHANICAL LINKAGE BETWEEN THE AIRFRAME AND THE ENGINE FUEL CONTROL TO POSITION THE FUEL CONTROL SPINDLE ACTUATORS ACCORDING TO COCKPIT POWER OR TRIM DEMANDS. THE XT701 ENGINE REQUIRES NO MECHANICAL LINKAGE BETWEEN THE AIRFRAME AND ENGINES AS FLY-BY-WIRE SYSTEMS ARE USED, AS SHOWN IN FIGURE 45. THIS GREATLY ENHANCES PROPULSION SYSTEM RELIABILITY, MAINTAINABILITY, AND SAFETY CHARACTERISTICS. SUCCESSFUL OPERATION OF THE FIRST FLY-BY-WIRE CONTROL ON AN ENGINE WAS IN FEBRUARY 1974.

ALLISON DESIGN REPORT NO. 8188 DATED APRIL 1974

#### REDUCED SPECIFIC FUEL CONSUMPTION (SFC) - OCTOBER 1974

ONE OF THE PRIME OBJECTIVES OF THE XT701 ENGINE PROGRAM WAS TO DEVELOP AN ENGINE WHICH HAS A LOW SPECIFIC FUEL CONSUMPTION OVER A WIDE RANGE OF POWER.

E. XT701-AD-700 ENGINE (CONTINUED)

THIS IS PARTICULARLY IMPORTANT FOR HELICOPTER ENGINES WHICH ARE SIZED FOR HOVER FLIGHT WITH ONE ENGINE FAILED AND THEREFORE CRUISE AT 50-60 PERCENT OF MAXIMUM POWER FOR THE MAJORITY OF THEIR MISSION. A T701 POWERED HELICOPTER WILL CONSUME APPROXIMATELY 1200 GALLONS OF JP4 DURING A DESIGN MISSION AS COMPARED WITH 1600-1950 GALLONS IF IT POSSESSED THE SFC CHARACTERISTICS REPRESENTED BY THE TECHNOLOGY LEVEL OF THOSE ENGINES CURRENTLY IN THE ARMY CARGO HELICOPTER INVENTORY. MEASURED XT701 PERFORMANCE OBTAINED IN OCTOBER 1974 DEMONSTRATED THAT THE ENGINE MET ITS SPECIFICATION FUEL CONSUMPTION REQUIREMENTS THROUGHOUT ITS ENTIRE POWER SPECTRUM, FIGURE 46.

ALLISON DESIGN REPORT NO. 8312 DATED 22 OCTOBER 1974

E. XT701-AD-700 ENGINE (CONTINUED)

FUTURE TECHNOLOGY GOALS - XT701-AD-700 ENGINE

CROSS-ROLLED TURBINE DISCS - APRIL 1975

AS PART OF THE ENGINE PROGRAM COST-OF-OWNERSHIP AND DESIGN-TO-COST EFFORTS, A PROGRAM TO DETERMINE THE FEASIBILITY OF FABRICATING TURBINE DISCS BY CROSS-ROLLING STEEL INCONEL 706 PLATE IS CURRENTLY IN PROCESS. THE GOAL OF THIS PROGRAM IS TO DEMONSTRATE THAT CROSS-ROLLING TECHNIQUES, AS ILLUSTRATED IN THE ATTACHED FIGURE 47, CAN PRODUCE TURBINE DISCS WITH PROPERTIES COMPARABLE TO WELL PROVEN INCONEL 718 FORGINGS AT APPROXIMATELY 50 PERCENT OF THE COST OF FABRICATION. PER THE ATTACHED FIGURE 48, IT IS ESTIMATED THAT A THIRD STAGE TURBINE WHEEL COULD BE FABRICATED USING THIS TECHNIQUE IN LIEU OF CONVENTIONAL FORGING FOR AN APPROXIMATE SAVINGS OF \$762 PER WHEEL. THIS FABRICATION TECHNIQUE WHEN ALLIED WITH INERTIA WELDING, IS GENERALLY APPLICABLE TO OTHER MILITARY AND COMMERCIAL GAS TURBINE ENGINES AND OFFERS THE POTENTIAL FOR SIGNIFICANT OVERALL SAVINGS.

ALLISON DESIGN REPORT NO. - TO BE DETERMINED

ENGINE SAFETY DEMONSTRATION - JUNE 1975

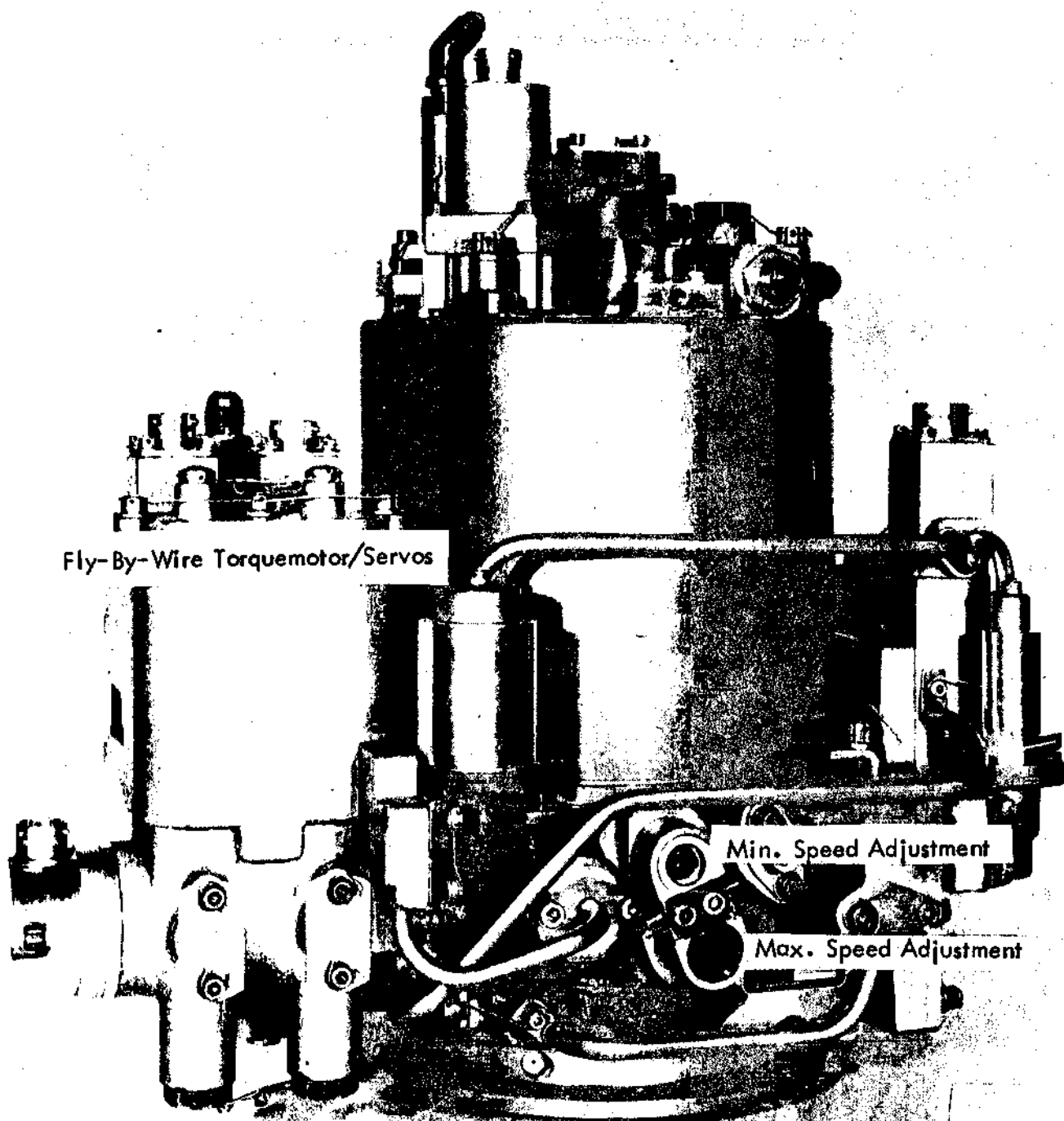
IN JUNE 1975 THE XT701 ENGINE WILL UNDERGO A FORMAL TEST INTENDED TO DEMONSTRATE THAT STRINGENT AIRWORTHINESS STANDARDS CAN BE MAINTAINED AFTER BEING SUBJECTED TO RIGOROUS OPERATING CYCLES, INCLUDING EXTENDED PERIODS OF OPERATION AT MAXIMUM OUTPUT POWER. SUCCESSFUL COMPLETION OF THIS TEST WILL SERVE AS THE BASIS FOR ISSUANCE OF A SAFETY FLIGHT RELEASE FOR USE IN THE HLH PROTOTYPE.

ALLISON DESIGN REPORT NO. - TO BE DETERMINED

### SHAFT HORSEPOWER/WEIGHT COMPARISON

<u>ITEM</u>	<u>HLH</u>	<u>CURRENT</u>	
		<u>CH-47</u>	<u>CH-54</u>
ENGINE MODEL	XT701-AD-700	T-55-L-11B	T-73
ENGINE SHP	8079	3400	4800
ENGINE WT	1179	710	981
SHP/LB	6.9	4.8	4.9
SFC	.471	.538	.690

**FIGURE 44**



**FIGURE 45 XT701 ENGINE HYDROMECHANICAL FUEL CONTROL**

**FIGURE 45**

# SPECIFIC FUEL CONSUMPTION (SFC)

COMPARATIVE DATA

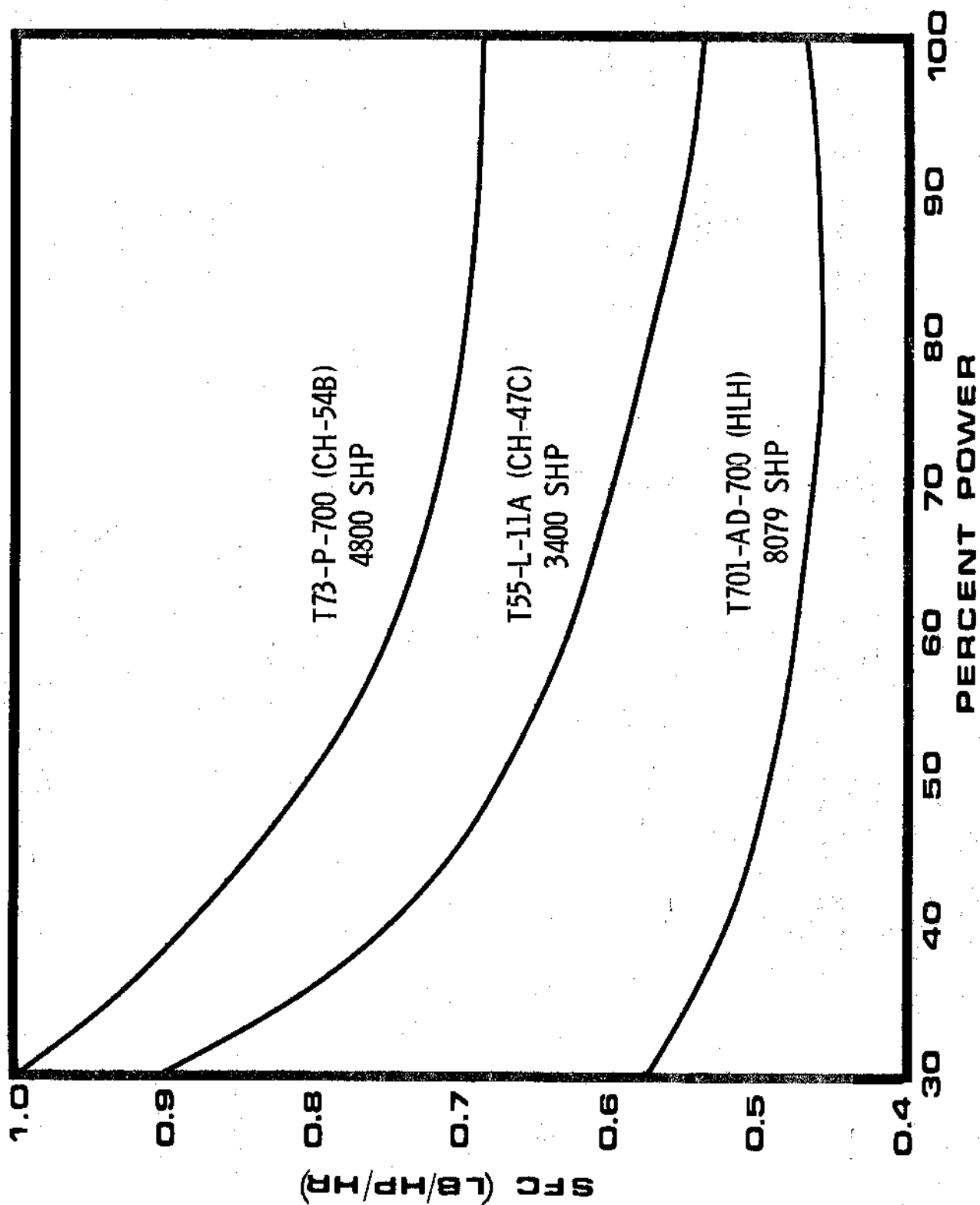


FIGURE 46

TECHNICAL HIGHLIGHTS - HIGH POTENTIAL COST REDUCTION  
CONTOUR CROSS-ROLLED PLATE PROCESSING

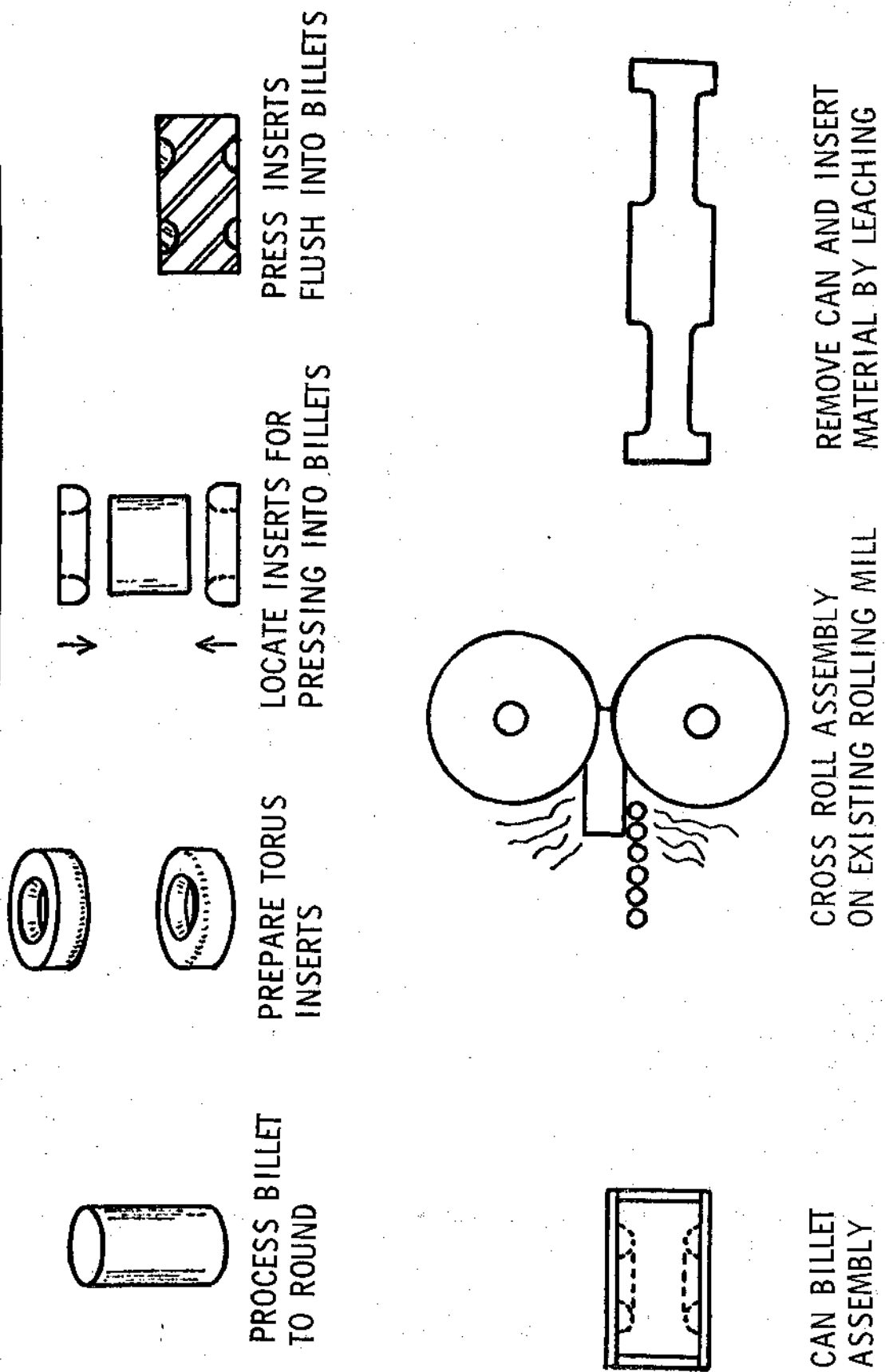


FIGURE 47

## CROSS-ROLLED PLATE

### COST COMPARISON CROSS-ROLLED PLATE VS. DIE FORGING

COST COMPARISON: 501-M62 THIRD STAGE TURBINE WHEEL  
PART NUMBER EX106012  
MATERIALS INCO 718 AND INCO 706  
QUANTITY - 14 PIECES

#### COST PER DISC - THIRD STAGE TURBINE WHEEL

	<u>INCO 718</u>	<u>INCO 706</u>
CLOSED DIE FORGING	\$975 EA.	\$975 EA.
CROSS-ROLLED PLATE	<u>500 EA.</u>	<u>425 EA.</u>
COST SAVINGS USING CROSS-ROLLED PLATE	\$475 EA.	\$550 EA.
COST SAVINGS IN MACHINING		<u>212 EA.</u>
COST SAVINGS USING INCO 706		\$762 EA.

NOTE: THIRD STAGE MACHINED TO FINISH DIMENSION  
(NO SHAFT WELD REQUIRED)

**FIGURE 48**

F. AIRFRAME

## F. AIRFRAME

### PAST TECHNOLOGY ACCOMPLISHMENTS - AIRFRAME

#### VIBRATION REDUCTION ACCOMPLISHMENTS - APRIL 1972 - NOVEMBER 1974

AS PART OF THE HLH ADVANCED TECHNOLOGY PROGRAM, A STUDY WAS CONDUCTED TO DETERMINE THE VIBRATION CHARACTERISTICS OF THE HLH AND TO EVALUATE AND RECOMMEND VARIOUS VIBRATION REDUCTION DEVICES WHICH MIGHT BE EMPLOYED TO IMPROVE VIBRATION LEVELS. RESULTS CONCLUDED THAT THE BEST APPROACH FOR THE HLH WAS A COMBINATION OF ROTOR MOUNTED PENDULUM FLAP ABSORBERS AND CREW AREA ISOLATION. THE PROTOTYPE AIRCRAFT WILL HAVE DYNAMIC ANTI-RESONANCE VIBRATION ISOLATOR (DAVI) UNITS BETWEEN THE AIRFRAME AND COCKPIT FLOOR MODULE AND THE LOAD CONTROLLING CREW MEMBER STATION AND THEIR OPERATION IS DESCRIBED IN FIGURE 49. PRELIMINARY BENCH TESTS OF DAVI UNITS ARE ENCOURAGING, INDICATING THAT THE DAVI UNITS ARE VERY EFFECTIVE. THIS HAS DEMONSTRATED THE EFFECTIVENESS OF THE DAVI CONCEPT TO REDUCE VIBRATION LEVELS IN THE COCKPIT ENVIRONMENT BELOW MINIMUM SPECIFICATION REQUIREMENTS. SHAKE TESTING OF THE HLH COCKPIT FLOOR INCLUDING PILOT, COPILOT, FLIGHT ENGINEER SEATS AND INSTRUMENT PANEL IS IN PROGRESS.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

#### LANDING GEAR - MAY 1973

THE HLH MAIN LANDING GEAR, FIGURE 50, IS THE LARGEST HELICOPTER CRANE CONFIGURED GEAR EVER FABRICATED (LARGER THAN THE DC-10 MAIN GEAR) HAVING THE REQUIREMENT OF HIGH DAMPING TO PRECLUDE GROUND RESONANCE SUPERIMPOSED UPON A HIGH SINK SPEED CAPACITY OF UP TO 16.9 FEET PER SECOND WITHOUT STRUCTURAL DAMAGE. THIS GEAR IS CURRENTLY BEING FABRICATED.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

## F. AIRFRAME (CONTINUED)

### PROTOTYPE FUSELAGE CONSTRUCTION - JULY 1973

THE FUSELAGE WAS TO BE SEMI-MONOCOQUE FRAME (STRINGERS AND STRESSED ALUMINUM SKIN) CONSTRUCTION. THE PRINCIPAL MATERIALS USED IN THE CONSTRUCTION OF THE FUSELAGE WOULD HAVE BEEN HIGH STRENGTH BARE AND/OR AL CLAD ALUMINUM ALLOY. DURING DESIGN ITERATIONS A MAJOR CHANGE WAS TO DISCARD OLD FUSELAGE TECHNOLOGY AND FABRICATE THE FUSELAGE FROM BONDED ALUMINUM HONEYCOMB IN ORDER TO REALIZE SIGNIFICANT REDUCTIONS IN WEIGHT, COST, AND PARTS COUNT. THE PROTOTYPE HLH WILL BE THE FIRST AND LARGEST AIRFRAME CONSTRUCTED COMPLETELY OF BONDED ALUMINUM HONEYCOMB SKIN PANELS. FUSELAGE EXTERNAL CONTOURS WERE MATHEMATICALLY DERIVED AND TAPES WERE USED DIRECTLY TO CUT MOLE TEMPLATES ON COMPUTER CONTROLLED MACHINES WITHOUT THE TIME CONSUMING EXPENSE OF INTERMEDIATE LOFTING AND DRAFTING. THE NEW LIGHTWEIGHT BONDED TOOLING CONCEPT USED ON THE PROTOTYPE TO FORM THE BONDED HONEYCOMB SKIN PANELS ALONG WITH THE USE OF MACHINE CUT TEMPLATES HAS PROVIDED TOOLING THAT IS REUSABLE.

BOEING VERTOL DOCUMENT NO. DCD301-001 DATED JULY 1973

### COMPUTER MODELING IN AIRFRAME DESIGN - SEPTEMBER 1974

THE HLH IS THE FIRST TANDEM ROTOR HELICOPTER TO EMPLOY NASTRAN COMPUTER MODELING DURING THE DESIGN PHASE, FIGURE 51. THIS MODEL WAS UTILIZED TO PREDICT VIBRATION LEVELS, MODE SHAPES AND OTHER AREAS OF HIGH STRESS, FIGURE 52. THE PROTOTYPE XCH-62 PRESENTLY UNDER CONSTRUCTION WILL HAVE STIFFENERS INSTALLED FOR TUNING THE AIRFRAME MODES AWAY FROM PRIMARY EXCITATION FREQUENCY, THEREBY REDUCING THE RESULTANT VIBRATION LEVELS. THESE STIFFENERS ARE CONSTRUCTED FROM ADVANCED COMPOSITE MATERIALS, THEIR CONFIGURATION HAVING BEEN DETERMINED BY NASTRAN TECHNIQUES. FLIGHT TEST OF THE PROTOTYPE WILL VALIDATE THE ADVANCED NASTRAN STIFFENING AND MODELING TECHNIQUES.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

## F. AIRFRAME (CONTINUED)

### FUTURE TECHNOLOGY GOALS - AIRFRAME

#### FUSELAGE SPLICE - MARCH 1975

COMPLETION OF THE AIRFRAME (FUSELAGE SPLICE) IN MARCH 1975 SIGNIFIES A SIGNIFICANT TECHNICAL MILESTONE AS THE COMBINATION OF A JOINT ENGINEERING AND OPERATIONS EFFORT TO REDUCE THE WEIGHT AND COST OF FUTURE AIRCRAFT. AT ROLLOUT IN OCTOBER 1975, THIS AIRCRAFT WILL HAVE THE LARGEST BONDED HONEYCOMB SEMI-MONOCOQUE FUSELAGE EVER CONSTRUCTED. THE TWO INCLOSED CHARTS, FIGURES 53 AND 54, ILLUSTRATE THE BENEFITS OF HONEYCOMB CONSTRUCTION.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

#### LANDING GEAR DROP TEST - MAY 1975

SUCCESSFUL COMPLETION OF DROP TESTS IN MAY 1975 WILL BE A SIGNIFICANT TECHNICAL ACHIEVEMENT. FLIGHT TESTING BEGINNING IN MARCH 1976 OF THIS LARGE GEAR WILL VALIDATE DESIGN CRITERIA.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

#### FLIGHT TESTING OF FUSELAGE STIFFENERS - MARCH-OCTOBER 1976

ADVANCE KNOWLEDGE GENERATED BY NASTRAN MODELING WILL PROVIDE FOR A MORE OBJECTIVE AND DETAILED FLIGHT TEST. DURING FLIGHT TEST THE FUSELAGE STIFFENERS, EASILY ACCESSIBLE, CAN BE READILY CHANGED. THIS WILL ALLOW FOR OPTIMIZATION OF THE FLIGHT VEHICLE VIBRATORY LEVELS BASED ON THE MOST CURRENT TEST DATA.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

F. AIRFRAME (CONTINUED)

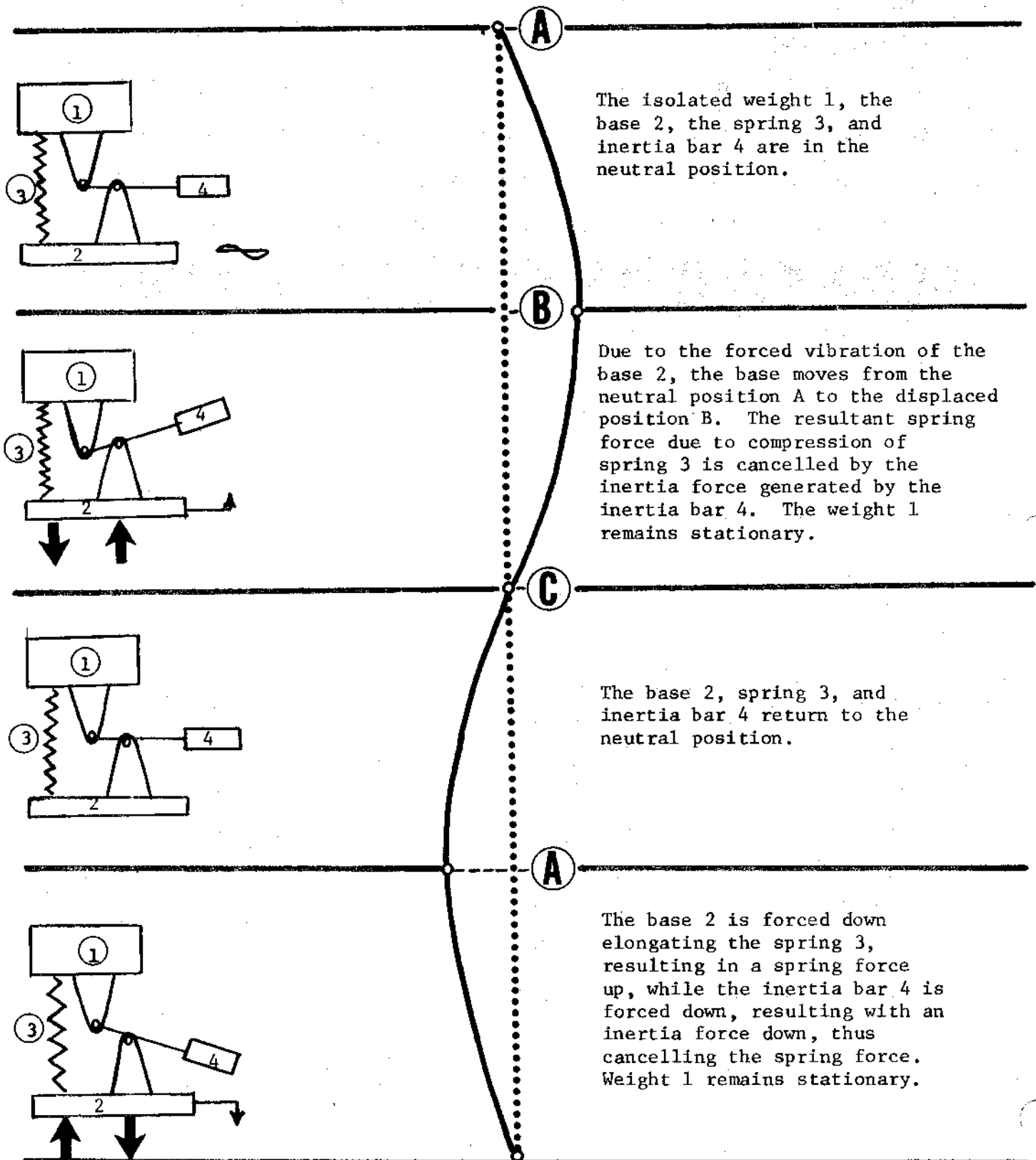
FLIGHT TEST OF DYNAMIC ANTI-RESONANCE VIBRATION ISOLATORS (DAVI) -  
MARCH-OCTOBER 1976

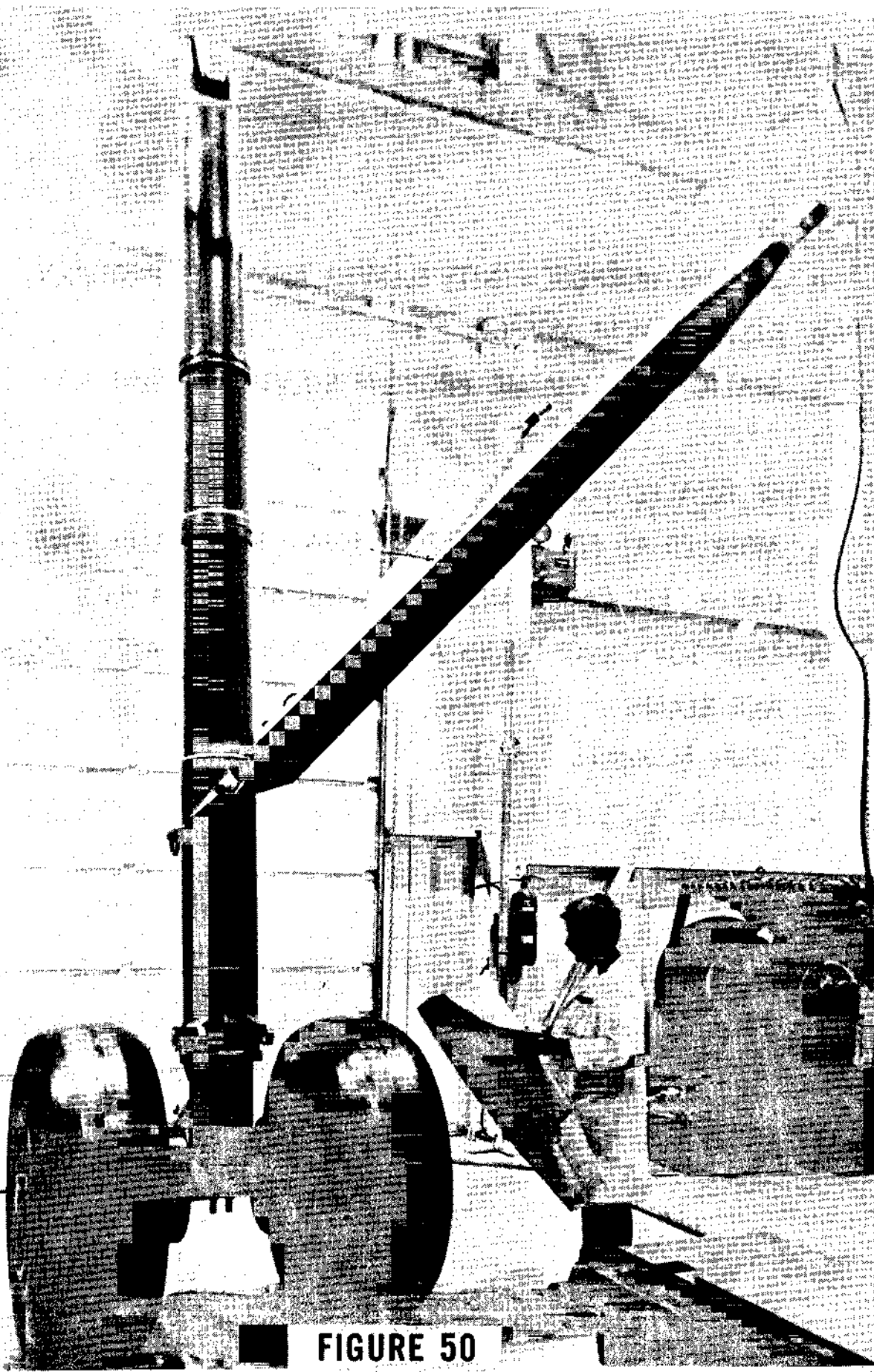
RESULTS OF THE LABORATORY SHAKE TESTS WILL BE REVIEWED, CHANGES MADE TO THE CONFIGURATION AS REQUIRED FOR THE PROTOTYPE. THIS HARDWARE WILL THEN BE INSTALLED AND FLIGHT TESTED IN THE PROTOTYPE HLH BEGINNING IN MARCH 1976. COMPARED TO OTHER CONCEPTS INVOLVING MULTI-FREQUENCY CREW ISOLATION, THE DAVI SYSTEM IS LEAST COMPLEX, LOWEST WEIGHT AND INCURS THE LOWEST DEVELOPMENT AND PRODUCTION COSTS.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

# DAVI IN OPERATION

THE FOLLOWING SKETCHES SHOW THE DAVI ALPHA IN OPERATION.





**FIGURE 50**

HLH FUSELAGE CRITERIA  
NASTRAN COMPUTER PROGRAM

NASTRAN

- o GENERAL PURPOSE FINITE ELEMENT ANALYSIS PROGRAM
- o DISPLACEMENT METHOD
- o STATIC AND DYNAMIC PROBLEM SOLVING CAPABILITY

FUSELAGE IDEALIZATION

- o MODELED AS FOUR SUBSTRUCTURES - FWD PYLON, FWD CABIN, AFT CABIN AND STUB WING AND AFT PYLON
- o EACH SUBSTRUCTURE IS A CONNECTION OF PLATES, RODS AND BEAMS.
- o TOTAL ELEMENTS - 3100
- o ELEMENT SIZE IS ACCOMPLISHED BY A MANUAL STRESS ANALYSIS

ANALYSIS

- o DYNAMIC ANALYSIS YIELDS NATURAL FREQUENCIES AND MODES, FORCED RESPONSE AT ANY FREQUENCY, DYNAMIC STRESSES, MODAL PARTICIPATION OF FORCED RESPONSE.

**FIGURE 51**

# MODEL STATISTICS

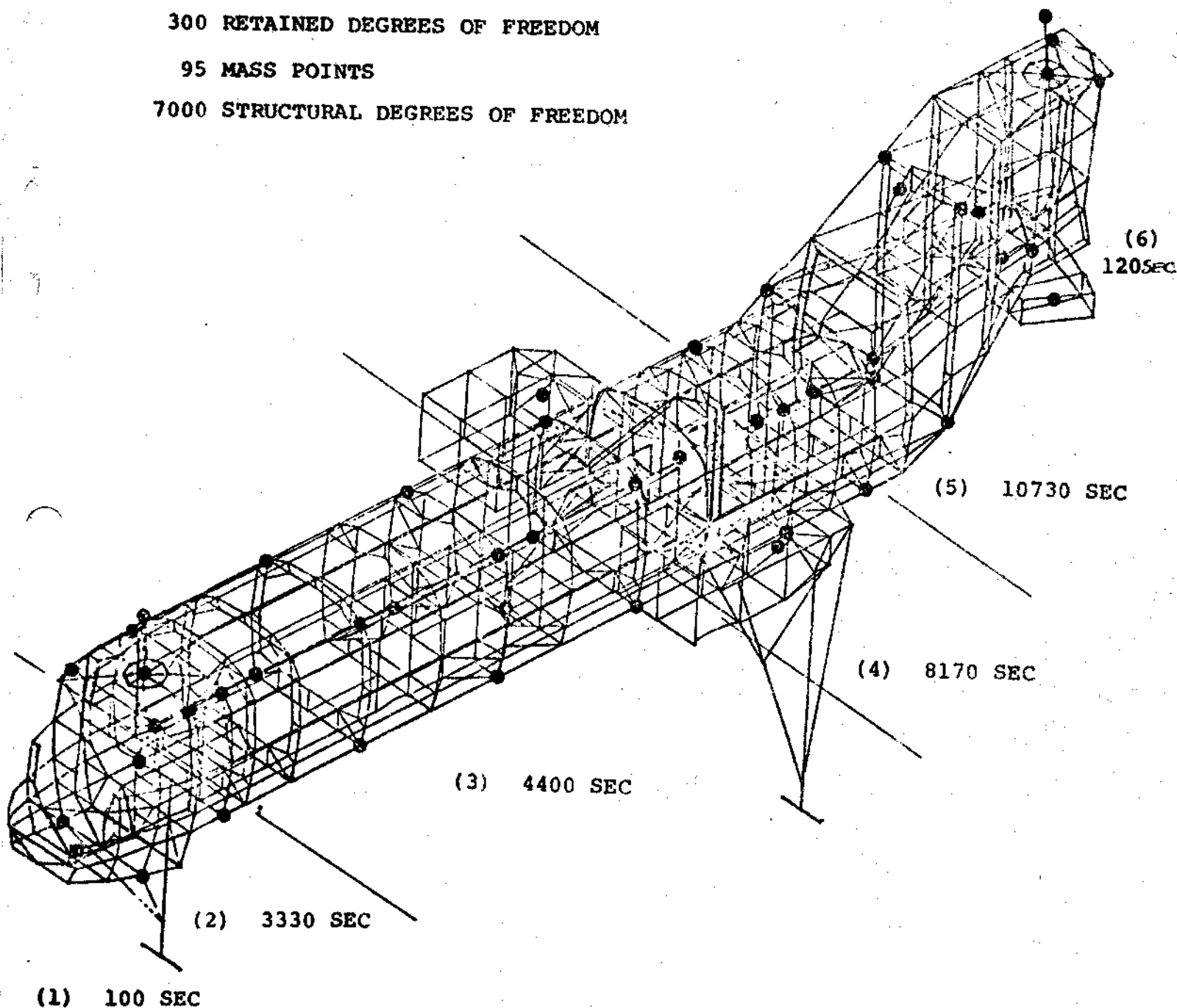
1180 NODES

3100 STRUCTURAL ELEMENTS

300 RETAINED DEGREES OF FREEDOM

95 MASS POINTS

7000 STRUCTURAL DEGREES OF FREEDOM



**FIGURE 52**

**POTENTIAL BENEFITS OF PRODUCTION HONEYCOMB STRUCTURE**

- 0 WEIGHT SAVING
- 0 INCREASED FATIGUE LIFE
  - 0 REDUCED NUMBER OF FASTENERS
- 0 REDUCED PARTS COUNT
  - 0 REDUCED DETAIL PARTS FAB
  - 0 REDUCED DETAIL TOOLING
  - 0 LIGHTER SKIN GAGES - LESS FORMING
  - 0 REDUCED ASSEMBLY MANHOURS

**FIGURE 53**

## HONEYCOMB VS. SKIN AND STRINGERS

### SUMMARY

SKIN AND STRINGER FUSELAGE	11,700 LB.
ADVANCED MATERIAL AND COMPOSITES (PIDD WEIGHT)	10,180 LB. (-13 %)
HONEYCOMB FUSELAGE POTENTIAL	9,100 LB. (-22.3 %)
POTENTIAL HONEYCOMB FUSELAGE SAVINGS	1,080 LB.
PARTS COUNT REDUCTION	23.7 %

USE OF COMPOSITES COULD RESULT IN MEETING STIFFNESS REQUIREMENT AT NO WEIGHT INCREASE, MEETING STIFFNESS CRITERIA WITH ALUMINUM WILL RESULT IN A 600 LB. WEIGHT INCREASE.

**FIGURE 54**

#### G. SUBSYSTEMS

## G. SUBSYSTEMS

### PAST TECHNOLOGY ACHIEVEMENTS - SUBSYSTEMS

#### COCKPIT INSTRUMENTS - JULY 1973

VERTICAL TAPES OFFER SIGNIFICANT CONTRIBUTIONS TO REDUCING THE PILOT'S WORKLOAD. DUE TO THE HLH MISSION REQUIREMENT FOR LONG-TERM HOVERING, THE CREW MUST SPEND MAXIMUM TIME WITH THEIR HEADS OUT OF THE COCKPIT. VERTICAL TAPE INSTRUMENTATION, FIGURE 55, WAS USED TO ALLOW THE PILOT TO OBTAIN ALL PERTINENT INFORMATION ON VITAL ENGINE AND TRANSMISSION TEMPERATURES AND PRESSURES AT A GLANCE. UP TO THIS TIME, HOWEVER, VERTICAL TAPES WERE NOT PROVING TO BE RELIABLE PIECES OF EQUIPMENT. HIGH HEAT BUILDUP AND VIBRATION SUSCEPTIBILITY COMBINED TO EFFECT POOR RELIABILITY AND VERY LOW MTBF. DUE TO BOEING VERTOL'S EFFORTS IN SPECIFYING THEIR REQUIREMENTS AND THROUGH CLOSE DESIGN COOPERATION WITH GULL AIRBORNE INSTRUMENTS, INC. (BOEING'S VENDOR FOR VERTICAL TAPES), INSTRUMENTS WERE DEVELOPED THAT VIRTUALLY ELIMINATED HEAT BUILDUP, THUS RESOLVING THE MAJOR PROBLEM ASSOCIATED WITH PAST VERTICAL TAPE EXPERIENCE. IN ADDITION, GULL AIRBORNE INSTRUMENTS THROUGH UTILIZING THEIR PAST HELICOPTER EXPERIENCE IN PACKAGING THIS NEW GENERATION INSTRUMENT, MINIMIZED THE EFFECTS OF AIRFRAME VIBRATION. THESE DEVELOPMENTS ARE EXPECTED TO INCREASE RELIABILITY ON A PER CHANNEL BASIS TO APPROXIMATELY THREE TIMES THAT PRESENTLY EXPERIENCED WITH SIMILAR SINGLE CHANNEL INDICATORS. THIS IS A SIGNIFICANT ACCOMPLISHMENT WHICH WILL DEFINITELY SPILL OVER INTO OTHER ARMY AIRCRAFT. BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

G. SUBSYSTEMS (CONTINUED)

CRASHWORTHY FUEL SYSTEM - AUGUST 1974

THE OBJECTIVE OF THE CRASHWORTHY FUEL SYSTEM DEVELOPMENT WAS TO DESIGN AND TEST THE LARGEST CRASHWORTHY FUEL SYSTEM EVER ATTEMPTED BY THE ARMY. IN AUGUST 1974 THE CONTRACTOR SUCCESSFULLY DROP TESTED FROM A HEIGHT OF 65 FEET A FUEL CELL CONTAINING 5025 POUNDS OF LIQUID. THIS HAS BEEN THE LARGEST FUEL CELL DEVELOPED AND TESTED TO DATE.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

## G. SUBSYSTEMS (CONTINUED)

### FUTURE TECHNOLOGY GOALS

#### ENVIRONMENTAL CONTROL UNIT (ECU) - MARCH-OCTOBER 1976

THE HLH ENVIRONMENTAL CONTROL UNIT, FIGURE 56, IS AN AIR CYCLE TYPE OF DEVICE. IT IS UNIQUE IN THAT ONLY HALF OF THE HIGH TEMPERATURE HIGH PRESSURE AIR REQUIRED FOR ITS OPERATION COMES FROM THE MAIN ENGINES OR APU. PRESENT ECU'S REQUIRE THAT ALL AIR COME FROM THE ENGINES OR APU. THE REMAINDER OF THE AIR REQUIRED FOR ITS OPERATION IS RECIRCULATED FROM THE CREW COMPARTMENT. THUS, REDUCED ENGINE OR APU BLEED AIRFLOW RESULTS IN A FUEL CONSUMPTION SAVINGS OF 7 GALLONS PER HOUR. THIS DEVICE WILL BE INSTALLED IN THE PROTOTYPE HLH AND FLIGHT TESTED UNDER DIFFERENT CONDITIONS.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

#### FLIGHT TEST OF VERTICAL TAPE INSTRUMENT - MARCH-OCTOBER 1976

FROM MARCH 1976 THRU THE END OF THE FLIGHT TEST PROGRAM, THE PROTOTYPE AIRCRAFT WILL BE FLYING USING VERTICAL TAPE APPLICATION IN MANY PRIMARY INSTRUMENTS TO SUPPLY THE PILOT WITH VITAL FLIGHT INFORMATION. VERTICAL TAPE INSTRUMENTS SHOULD BE NOT ONLY RELIABLE, BUT SIGNIFICANTLY MORE RESPONSIVE TO THE PILOT'S NEEDS AND COULD BE WIDELY ADOPTED BY THE HELICOPTER INDUSTRY.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

#### CRASHWORTHY FUEL SYSTEM FLIGHT TEST - MARCH-OCTOBER 1976

THE GOAL OF THIS PROGRAM IS TO PROVIDE A SAFE FLIGHT TEST ENVIRONMENT IN ADDITION TO THE TEST AND EVALUATION OF A LARGE CRASHWORTHY FUEL SYSTEM IN A FLIGHT ENVIRONMENT. IN THE EVENT OF A CATASTROPHIC FAILURE AND CRASH OF THE HLH, THIS SYSTEM WILL MINIMIZE THE EFFECTS OF POSTCRASH FIRE AND PROVIDE PROTECTION FOR THE CREW.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED

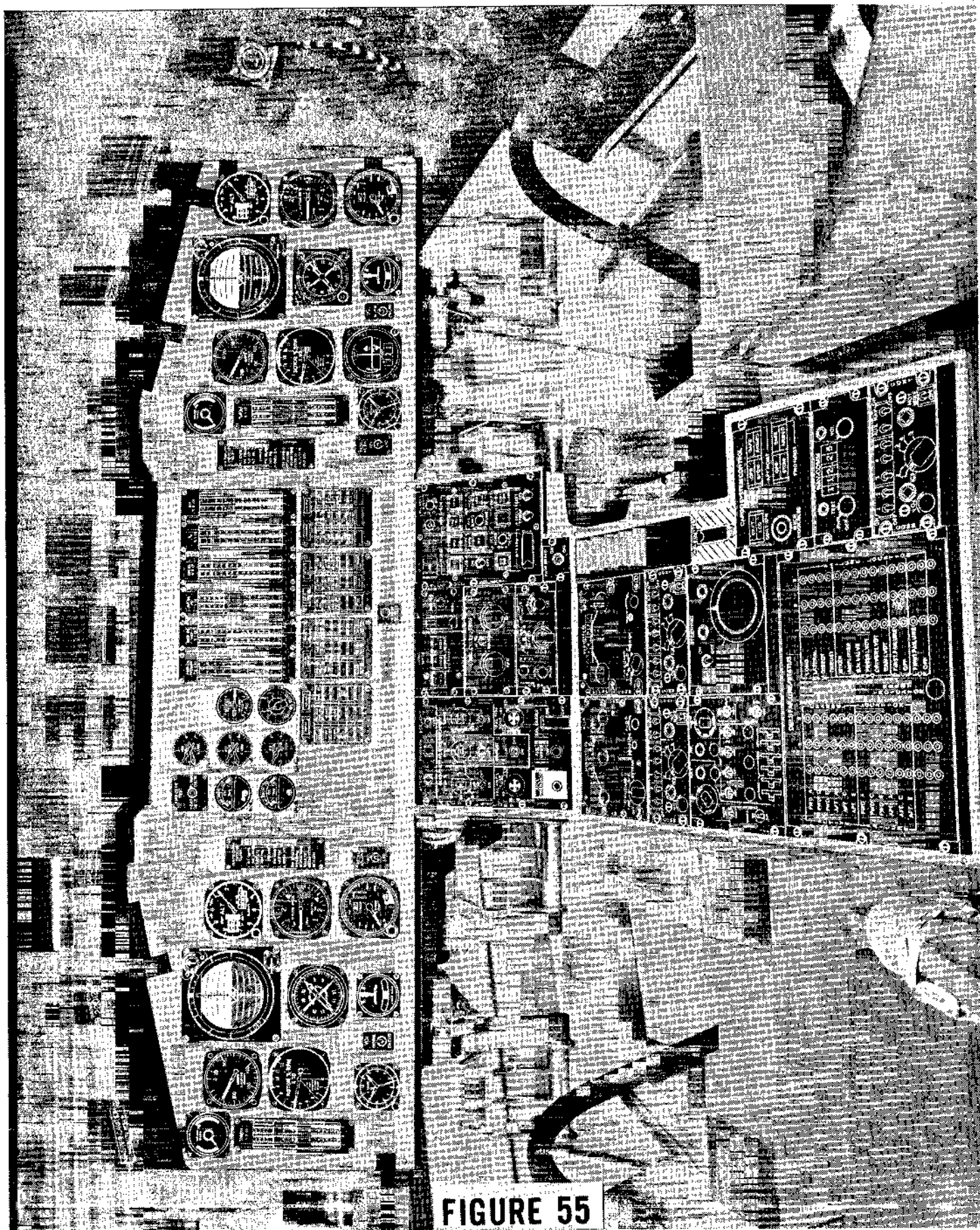
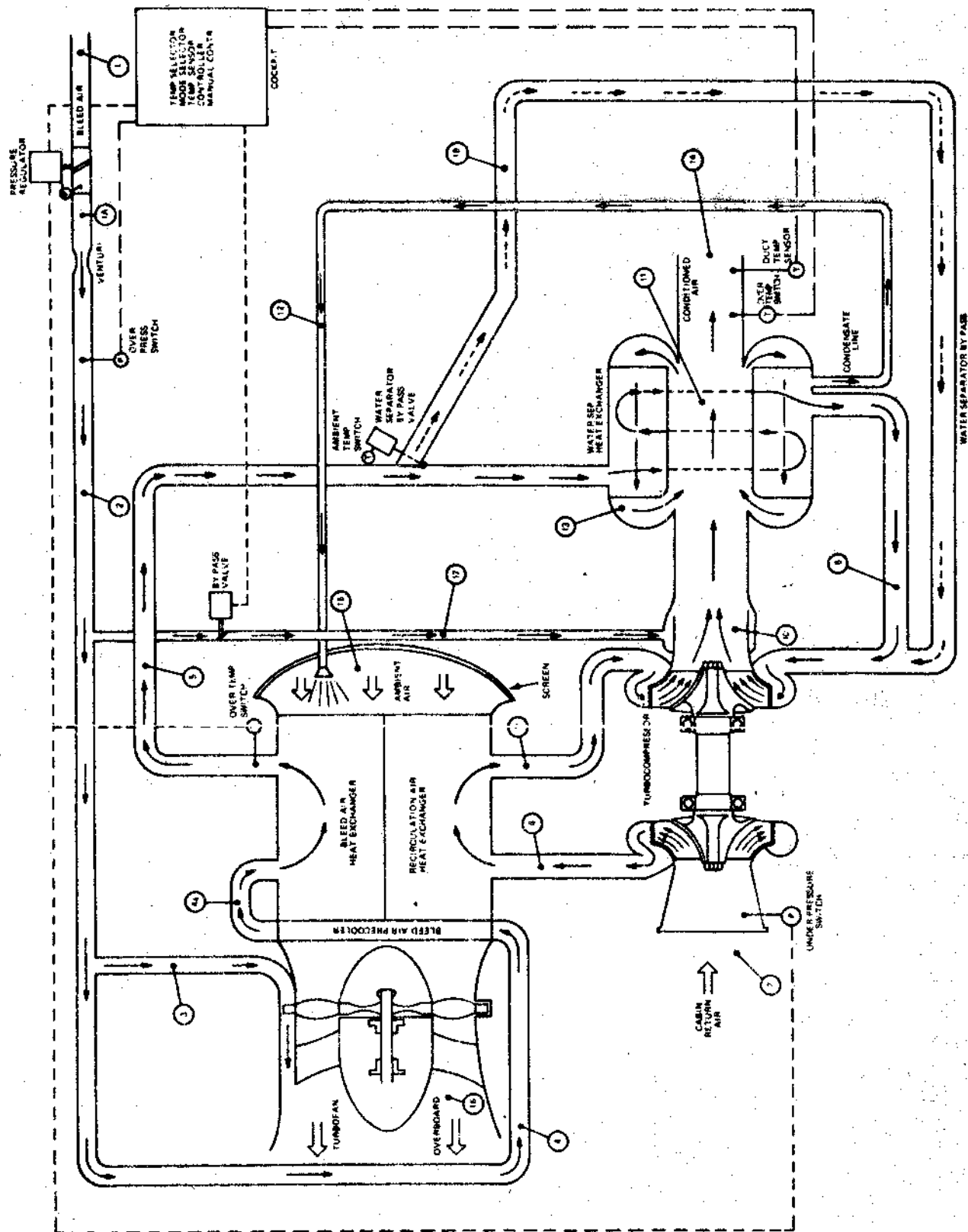


FIGURE 55



**FIGURE 56**

#### H. MATERIALS

## H. MATERIALS

### PAST TECHNOLOGY ACHIEVEMENTS

#### TITANIUM MATERIALS EVALUATION PROGRAM

ENGINEERING MATERIAL PROPERTIES HAVE BEEN DEVELOPED FOR A 9 X 16 X 36 INCH 6A1-4V TITANIUM ALLOY BILLET FINISH FORGED IN THE ALPHA-BETA RANGE AND SUBSEQUENTLY PROCESSED TO THE SOLUTION TREATED AND OVERAGED (STOA) CONDITION. THESE PROPERTIES WERE OBTAINED FOR POTENTIAL APPLICATION IN THE DESIGN OF LARGE FATIGUE CRITICAL FORGED TITANIUM HELICOPTER DYNAMIC SYSTEM COMPONENTS. STATIC STRENGTH, SMOOTH AND NOTCHED AXIAL FATIGUE STRENGTH, FRETTED FATIGUE STRENGTH, FATIGUE CRACK PROPAGATION, AND FRACTURE TOUGHNESS DATA WERE OBTAINED. FATIGUE STRENGTH DATA WHICH INDICATE THE INFLUENCES OF SHOTPEENING AND THE USE OF COATINGS TO INHIBIT FRETTING WERE ALSO OBTAINED. THE ELEMENTS OF THIS TEST PROGRAM WERE STRUCTURED TO PROVIDE INTERRELATING PIECES OF DATA OFTEN REQUIRED IN A PARTICULAR SEQUENCE. A FLOW DIAGRAM, INDICATING THE MAJOR ELEMENTS OF THE PROGRAM, IS SHOWN IN FIGURE 57.

BOEING VERTOL DOCUMENT NO. - T301-10168-1 DATED MARCH 1973

#### LARGE BEARING TEST RIG DESIGN - JUNE 1973

LONG TERM HIGH SPEED FATIGUE TEST RIGS HAD BEEN AVAILABLE FOR BALL AND ROLLER BEARINGS FOR SOME TIME. HOWEVER, WHEN THE HLH PROGRAM BEGAN NO TAPERED ROLLER BEARING RIGS EXISTED WHICH WERE CAPABLE OF PRODUCING LONG TERM FATIGUE DATA FOR TAPERED ROLLER BEARINGS OF THE HLH SIZE, SPEED, AND LOAD. THE HLH OBJECTIVE WAS TO PRODUCE A HIGH SPEED TAPERED ROLLER BEARING TEST RIG IN CONJUNCTION WITH NASA/LEWIS, WHICH WAS CAPABLE OF PRODUCING LONG TERM FATIGUE

#### H. MATERIALS (CONTINUED)

DATA ON BEARINGS OF HLH SIZE UNDER HLH CONDITIONS OF SPEED AND LOAD. A TEST RIG WAS DEVELOPED IN JUNE OF 1973 WHICH COULD SUBJECT BEARING TO LOADS AND SPEEDS EQUAL TO THOSE ENCOUNTERED IN THE HLH TRANSMISSIONS. THIS RIG COULD BE MODIFIED TO TEST OTHER SIZE HIGH SPEED TAPERED ROLLER BEARINGS USED IN APPLICATIONS WHERE THE SPEEDS ARE IN EXCESS OF 20,000 FT/MIN (BEARING DIAMETER IN FEET TIMES SHAFT SPEED IN RPM). THE CURRENT LIMIT TODAY IS 10,000 FT/MIN. NASA DOCUMENT NO. - CR134595 DATED JANUARY 1974

## H. MATERIALS (CONTINUED)

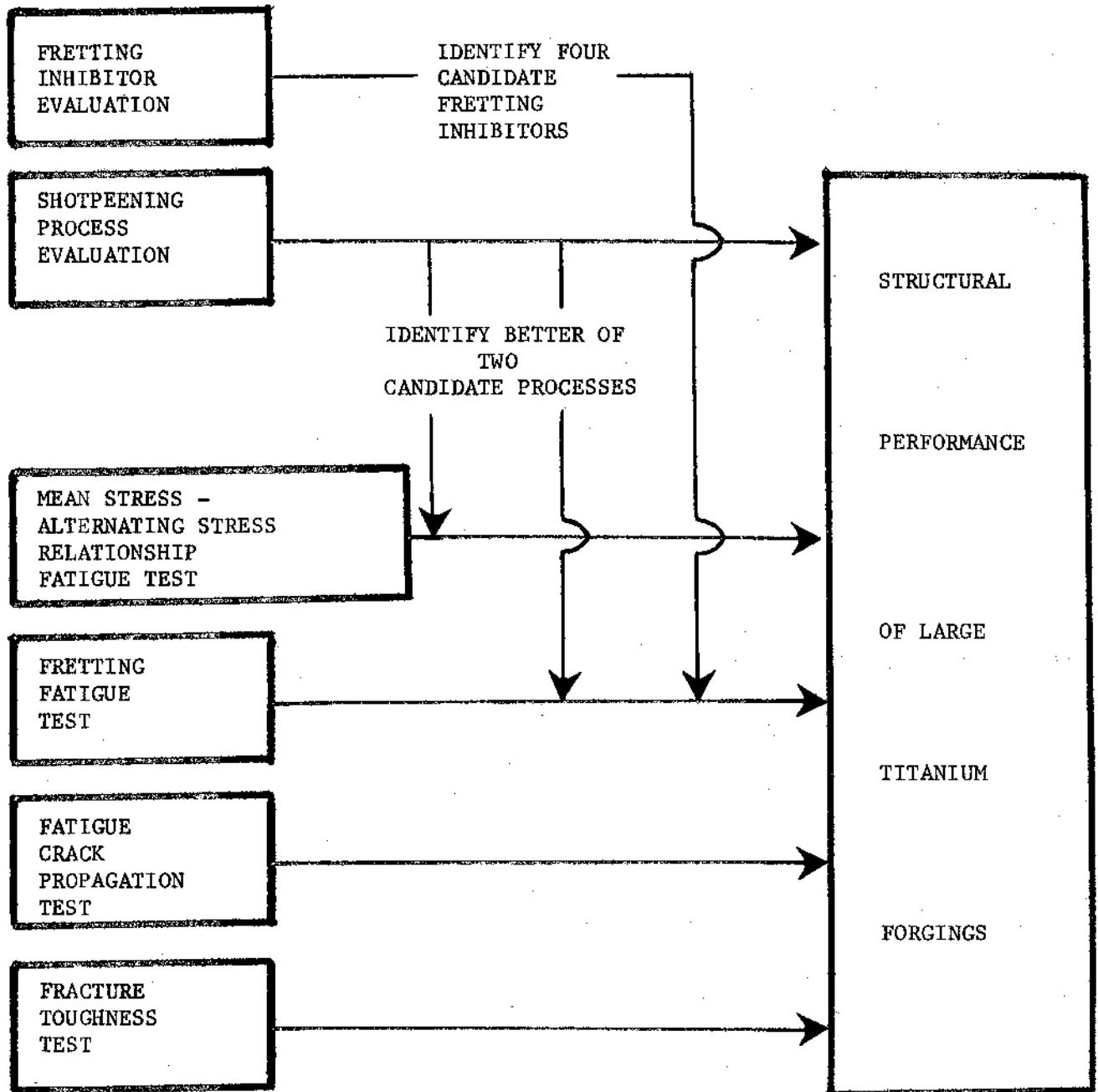
### FUTURE TECHNOLOGY GOALS - MATERIALS

#### HIGH SPEED TAPERED ROLLER BEARING TEST - SEPTEMBER 1975

TAPERED ROLLER BEARINGS HAVE AN ACCEPTED SPEED CAPABILITY OF 10,000 FT/MIN. THE ORIGINAL OBJECTIVE OF THIS PROGRAM WAS TO DO COMPARATIVE TESTING BETWEEN A BEARING DESIGNED BY A COMPUTER PROGRAM DEVELOPED UNDER THE LARGE BEARING DESIGN AND TEST PROGRAM AND THE CURRENT HLH DESIGNED BEARING. THE COMPUTER BEARING WAS DESIGNED IN CONJUNCTION WITH NASA/LEWIS AND WAS DEVELOPED WITH THE INTENT OF OPTIMIZING ALL POSSIBLE BEARING PARAMETERS WHICH COULD INFLUENCE EITHER LIFE OR OPERATING CAPABILITY. HLH DESIGNED BEARING TEST RIGS AND COMPUTER DESIGNED BEARINGS ARE CURRENTLY BEING PROCURED AND FABRICATED. THE TEST RIGS ARE BEING FABRICATED TO SPECIFICATIONS DEVELOPED UNDER THE HLH LARGE BEARING TEST RIG DESIGN (NASA DOCUMENT NO. CR134595 DATED JANUARY 1974). INITIAL TESTING OF BEARINGS WILL BEGIN IN SEPTEMBER OF 1975 AND WILL BE COMPLETED IN JUNE OF 1977 WITH PRELIMINARY RESULTS BECOMING AVAILABLE IN JUNE OF 1976. AS TEST RESULTS BECOME AVAILABLE, MORE SYSTEMS SHOULD BEGIN TO INCORPORATE TAPERED ROLLER BEARINGS INSTEAD OF CONVENTIONAL BALL AND ROLLER COMBINATIONS.

NASA DOCUMENT NO. - TO BE DETERMINED

# FLOW DIAGRAM FOR ELEMENTS OF TITANIUM MATERIALS EVALUATION PROGRAM



**FIGURE 57**

I. FLIGHT TEST PROGRAM

## I. FLIGHT TEST PROGRAM

### FUTURE TECHNOLOGY GOALS - FLIGHT TEST PROGRAM

#### PROTOTYPE XCH-62 GROUND TIE-DOWN TEST - FEBRUARY 1976

A 50-HOUR GROUND TIE-DOWN TEST WILL BE PERFORMED UTILIZING THE PROTOTYPE AIRCRAFT PRIOR TO INITIATION OF FLIGHT TEST. THIS TEST IS INTENDED TO VALIDATE THE INTEGRATION AND INTEGRITY OF ALL MAJOR SUBSYSTEMS AS CONFIGURED IN THE TEST VEHICLE. SUCH SYSTEMS AS THE TRANSMISSIONS, ROTOR BRAKE, ENGINES, SYNCHRONIZATION/ENGINE/ROTOR SHAFTS, ROTOR HUB/CONTROLS, FUEL CONTROLS, POWER MANAGEMENT SYSTEM, PNEUMATIC SYSTEM, ELECTRICAL/HYDRAULIC SYSTEMS, FUEL SYSTEM, FLIGHT CONTROLS, ETC., CAN BE FULLY TESTED DURING THIS TYPE EFFORT WHEREIN A DYNAMIC SYSTEMS TEST RIG PROVIDES ONLY LIMITED TEST CAPABILITY. SUCCESSFUL COMPLETION OF THIS TEST ASSURES A MORE SOUND TECHNICAL BASIS FOR FLIGHT TEST INITIATION AS WELL AS ASSOCIATED FLIGHT PROGRAM RISK REDUCTION.

#### PROTOTYPE XCH-62 FLIGHT TEST DEMONSTRATION - MARCH-OCTOBER 1976

THE FLIGHT TEST PROGRAM OF THE HLH IS DESIGNED TO PROVE FEASIBILITY AND DEMONSTRATE PERFORMANCE AND INTEGRATION IN A FLIGHT ENVIRONMENT OF ALL THE ADVANCED TECHNOLOGY COMPONENTS AND SYSTEMS IN THE LARGEST HELICOPTER DEVELOPED IN THE FREE WORLD. VALIDATION OF PREDICTED VERSUS ACTUAL PERFORMANCE OF THE ENTIRE AIRCRAFT SYSTEM WILL BE ACCOMPLISHED USING EXTENSIVE INSTRUMENTATION.

THE NEW BONDED HONEYCOMB STRUCTURE WITH ADVANCED COMPOSITE STIFFENING STRAPS TO OPTIMIZE FUSELAGE BENDING CHARACTERISTICS WILL BE EVALUATED

DURING THE FLIGHT TEST PROGRAM. THIS WILL DEMONSTRATE IN A FLIGHT ENVIRONMENT THE CAPABILITY AND STIFFENING CHARACTERISTICS OF THIS TYPE OF STRUCTURE IN A LARGE HELICOPTER. THE FLIGHT TEST PROGRAM WILL SURVEY THE FULL SPECTRUM OF THE PILOT AND CREW ENVIRONMENT IN A LARGE HELICOPTER. NOISE LEVELS AND METHODS OF ACOUSTICAL DAMPING WILL BE EVALUATED TOGETHER WITH THE NEW PENDULUM SYSTEM OF VIBRATION ABSORBERS INCORPORATED IN THE ROTOR SYSTEM WHICH WILL ELIMINATE THE 3 AND 4 PER REV. VIBRATIONS NORMALLY EXPERIENCED IN THIS TYPE HELICOPTER. THE COCKPIT FLOOR WILL BE ISOLATED BY DYNAMIC ANTI-RESONANCE VIBRATION ISOLATORS (DAVI) TO REDUCE VIBRATION FATIGUE OF THE PILOT. THE WORKLOAD REDUCTION BY THE NEW FLIGHT CONTROL SYSTEM, AUTOMATIC FUEL MANAGEMENT, NEW INSTRUMENTS AND DISPLAYS BEING DEVELOPED TO ENHANCE THE CREW'S ENVIRONMENT WILL BE DEMONSTRATED AND EVALUATED DURING FLIGHT TEST.

THE FLIGHT TEST PROGRAM WILL PROVIDE A TRAINING AND DATA BASE FOR PILOT TECHNIQUES AND OPERATION OF A LARGE CARGO HELICOPTER. THE CAPABILITY OF IN-FLIGHT ADJUSTMENT OF THE EXTERNAL CARGO ATTITUDE TO OPTIMIZE FLYING QUALITIES WILL BE DEMONSTRATED AND EVALUATED. THE OPERATION OF THE HLH IN A TWO-POINT EXTERNAL LOAD ATTACHMENT CONFIGURATION IN ADDITION TO FLYING CHARACTERISTICS WITHOUT EXTERNAL LOAD WILL BE EVALUATED AND THE BENEFITS TO PRESENT AND FUTURE HELICOPTER PROGRAMS DETERMINED.

TECHNOLOGY DEVELOPED AND DEMONSTRATED DURING THE HLH FLIGHT TEST PROGRAM  
WILL PROVIDE A SIGNIFICANT DATA BASE FOR USE ON ALL PRESENT AND FUTURE  
HELICOPTER PROGRAMS.

BOEING VERTOL DOCUMENT NO. - TO BE DETERMINED.

J. RELIABILITY, AVAILABILITY AND MAINTAINABILITY

J. RELIABILITY, AVAILABILITY AND MAINTAINABILITY (RAM)

RELIABILITY, AVAILABILITY AND MAINTAINABILITY (RAM) OBJECTIVES - JUNE 1971 -  
OCTOBER 1976

THE HLH DESIGN OBJECTIVES REGARDING RAM ARE GREATER THAN THE RAM LEVELS THAT HAVE BEEN ACHIEVED BY EXISTING HELICOPTER FLEETS. THE HLH DYNAMIC COMPONENTS OF THE ATC PROGRAM CONTAIN CONCEPTS WHICH REFLECT THE EMPHASIS OF OBTAINING HIGH LEVELS OF RELIABILITY THROUGH DESIGN INNOVATIONS IN PREFERENCE TO TEST AND MODIFICATION IMPROVEMENTS. THE MAINTAINABILITY OBJECTIVE OF 19.0 MAINTENANCE MANHOURS PER FLIGHT HOUR IS ALSO A FEATURE THAT HAS NOT BEEN ACCOMPLISHED IN EXISTING MILITARY HELICOPTER FLEETS. DESPITE THE LARGER SIZE AND GREATER PERFORMANCE OF THE HLH, THE MAINTENANCE DESIGN CONCEPT COUPLED WITH HIGH LEVEL OF RELIABILITY SHOWS A POTENTIAL OF INCREASED AVAILABILITY AND LOWERED LIFE CYCLE COSTS. WHILE THESE OBJECTIVES CANNOT BE TOTALLY DEMONSTRATED UNDER THE PRESENT PROGRAM, THE DESIGN CONCEPTS CAN, TO A CERTAIN DEGREE, BE VALIDATED THROUGH MONITORING FLIGHT TEST RESULTS IN SUCH AREAS AS SAFETY, CRITICAL FAILURES, MISSION ABORTS, REPAIR FREQUENCY, AND MAINTENANCE PROCEDURES.

K. PERFORMANCE

## K. PERFORMANCE

### FUTURE TECHNOLOGY GOALS - PERFORMANCE

#### COMPARISON OF HLH WITH MI-12

THE USSR MI-12 IS THE LARGEST HELICOPTER IN THE WORLD AND HAS THE GREATEST PAYLOAD CAPABILITY. THE HLH WILL BE 25 PERCENT SMALLER AND 45 PERCENT LIGHTER THAN THE MI-12, YET WILL HAVE A 50 PERCENT GREATER HOVER PAYLOAD CAPABILITY. THE MI-12 DOES NOT HAVE AN EXTERNAL PAYLOAD LIFT CAPABILITY AND THUS CANNOT PERFORM THE MAJORITY OF THE MISSIONS FOR WHICH THE HLH IS DESIGNED.

BOEING VERTOL DOCUMENT NO. - NOT APPLICABLE

#### HLH PAYLOAD CAPABILITY

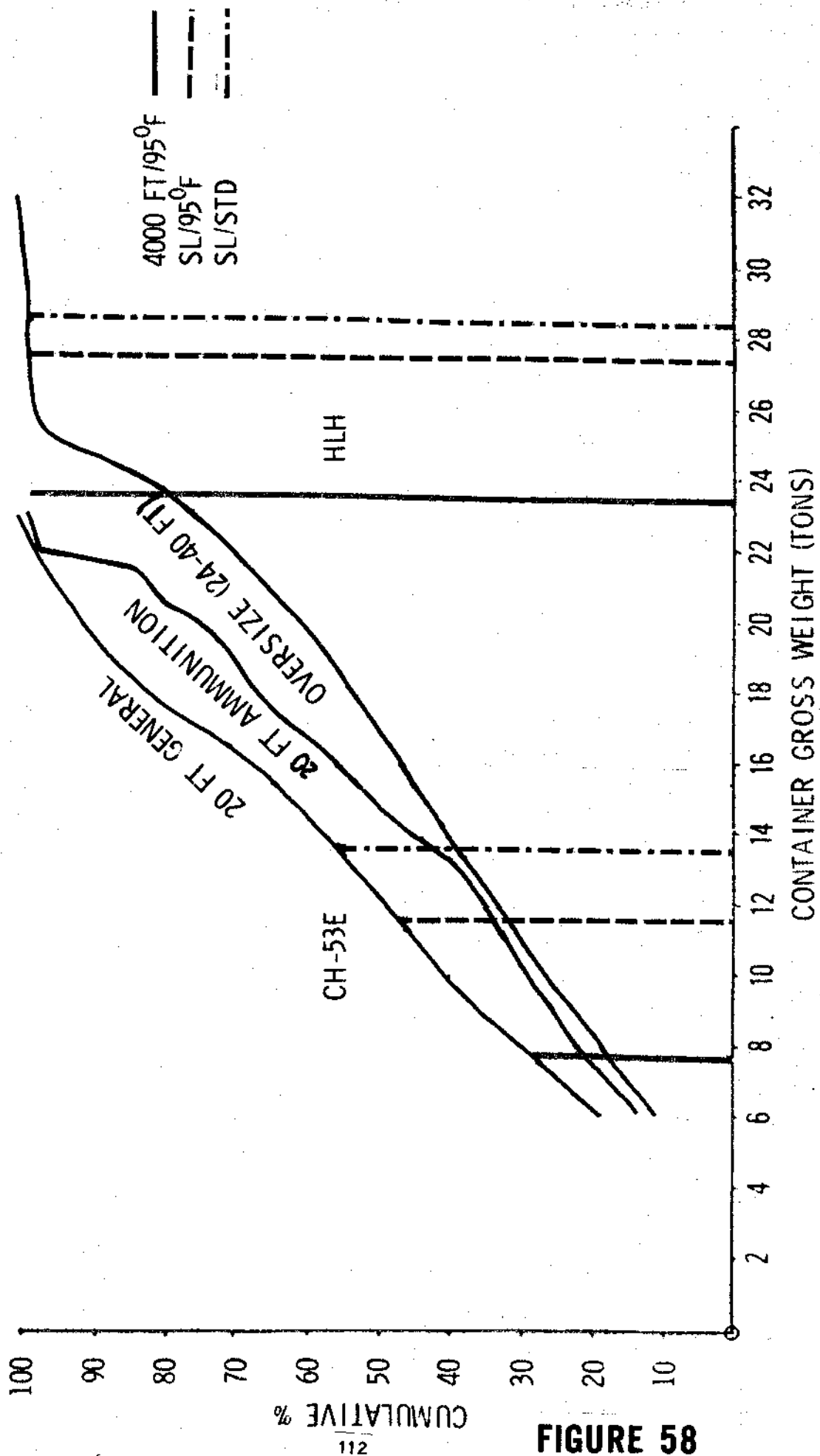
FIGURE 58 DEPICTS CONTAINER SHIPPING WEIGHT AND SIZE DISTRIBUTION FROM MILITARY TRAFFIC MANAGEMENT AND TERMINAL SERVICE (MTMTS) DATA FOR 1972. THIS IS THE SAME DATA AS EMPLOYED BY THE CONCEPTS ANALYSIS AGENCY FOR THE HLH COST AND OPERATIONAL EFFECTIVENESS ANALYSIS (COEA).

ALSO SHOWN ARE THE CAPABILITIES UNDER DIFFERENT AMBIENT CONDITIONS OF THE HLH (PROVIDED TO GAO BY THE ARMY IN JULY 1974) AND THE CH-53E (PROVIDED TO GAO BY THE NAVY IN AUGUST 1974).

THE CH-53E HAS THE GREATEST PAYLOAD CAPABILITY OF ANY EXISTING US HELICOPTER, BUT THE HLH PROVIDES A FAR GREATER LIFT CAPABILITY TO SATISFY THE ARMY'S TRANSPORTATION REQUIREMENTS.

BOEING VERTOL DOCUMENT NO. - NOT APPLICABLE.

# **CONTAINER MISSION CAPABILITY COMPARISON**



**FIGURE 58**